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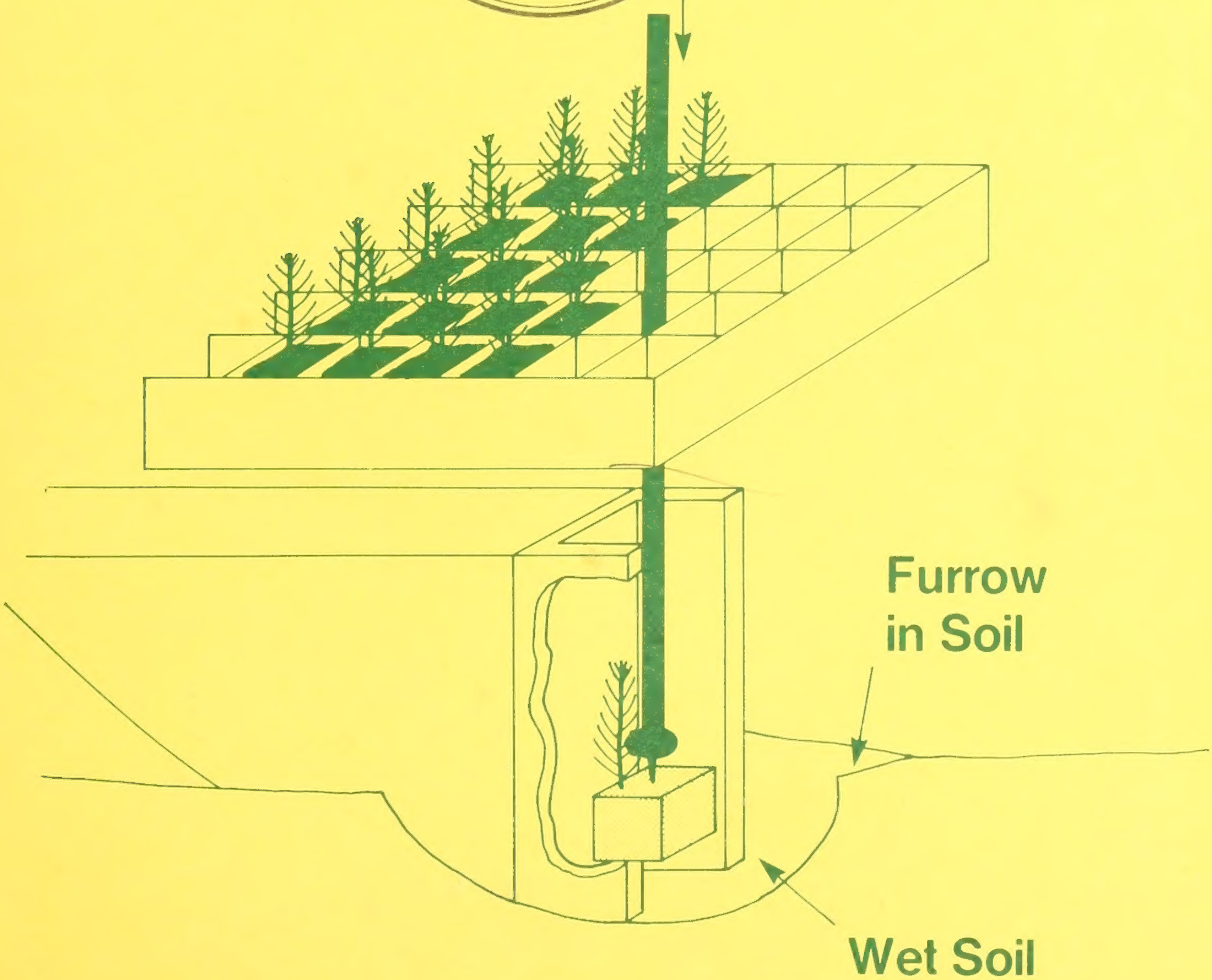
Proceedings, Combined Meeting of the Western Forest Nursery Associations:

Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association

**August 8-11, 1988
Vernon, British Columbia**



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Abstract

This proceedings is a compilation of 42 articles on various aspects of forest nursery management in western North America. Specific topics include: seed, bareroot seedling culture, container seedling culture, nursery management, seedling quality, nursery pests, nursery equipment, and outplanting performance. Of particular note are articles on the new nursery technology of container-bareroot transplants.

Note

As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential user as quickly as possible. To do this, we asked each author to assume full responsibility for submitting reviewed manuscripts in photoready format within tight deadlines. Thus, the manuscripts did not receive conventional Forest Service editorial processing, and consequently, you may find some typographical errors and slight differences in format. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA-Forest Service. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA-Forest Service.

On the cover: One step in the transplanting of "miniplugs" — small container seedlings that are started in the greenhouse and then transplanted to bareroot nursery beds (see Hee and others, p. 168)

USDA Forest Service
General Technical Report RM-167

December, 1988

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Technical Coordinator:

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Rocky Mountain Forest and Range
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Opening Remarks[1]

Peter Ackhurst[2]

Good morning Ladies and Gentlemen.

I appreciate the opportunity to take part in the combined meeting of these two organizations, whose work is so important. As nurserymen, you play a crucial role in the reforestation process, which is essential to the future of forest management.

To those of you from other Regions of Canada, the United States and elsewhere, I would like to welcome you to British Columbia. While your agenda over the next three days is a busy one, I trust you will be able to enjoy Vernon and the Okanagan Valley.

Before going any further, I would like to make a few comments for the benefit of any of you not familiar with the forestry and nursery situation in British Columbia. We have 54 million hectares (134 million acres) of forest land in British Columbia and 95 percent of that 54 million hectares is still publicly owned by the people of British Columbia. The Federal Government has one percent of the forest land holdings and the private sector has the remaining four percent. In the past the cost of reforestation on Crown land, including the cost of seed and seedlings, was typically paid by the Crown in the past through credits to stumpage.

The Forest Act was amended on December 17, 1987, to state explicitly that basic silviculture is the duty of both the Crown and the forest industry. The amendments are based on the principle that the process and cost of reforestation are responsibilities which are directly related to the privilege of harvesting timber from Crown land. Fully productive forests in the future are the aim of a newly strengthened commitment to reforestation.

Basic silviculture ensures the establishment of a free growing crop of commercially valuable trees. Detailed requirements for basic silviculture will be enforced with new regulations which apply to both government and industry.

The government's funding requirements for basic silviculture will decrease as remaining obligations on past harvests are met. With the exception of some residual maintenance activities, all these remaining obligations will be addressed during the current five year program. Beyond this, the government's funding requirements for basic silviculture will depend primarily on fire and pest damage.

The cost of basic silviculture on Crown land harvested under the Small Business Forest Enterprise Program (SBFEP) will be covered by the price industry pays for the timber harvested. The government will continue to administer basic silviculture required under the program on behalf of small business operators.

The forest industry is responsible, as of October 1, 1987, for reforesting areas harvested under major licences. As mentioned previously, in the past, the cost of reforestation on Crown land, including the cost of seed and seedlings, was typically paid by the Crown through credits to stumpage. This cost is now borne fully by industry. The trees established on Crown land are the property of the Crown. The Ministry of Forests audits industry's silviculture performance and has authority to penalize licensees for non-compliance under the Forest Act and regulations.

Before harvesting timber under a major licence, the forest industry is now required to submit a pre-harvest silviculture prescription. This prescription must comply with the regulations under the Forest Act and be sufficient to ensure basic silviculture.

Our first forest nursery was established in 1927, but by 1938 only 526 hectares (1300 acres) had been planted, the program expanded during the war years and by the end of 1945 we were operating three nurseries. By 1976, in response, particularly from 1965, to pressure from the forest industry and the public, the reforestation program had expanded. Nine nurseries were now in operation, with the capability of producing in excess of 80 million bareroot seedlings and 20 million container seedlings.

In 1980 the government started a program of contracting out the growing of seedlings. The Ministry of Forests tree nurseries produced about 100 million seedlings in recent years, or

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[1]Opening remarks presented at the combined meeting of the Western Forest Nursery Council and the Forest Nursery Association of British Columbia, Vernon, B.C., August 8-11, 1988.

[2]Peter W. Ackhurst, Acting Director, Silviculture Branch, Ministry of Forests, Victoria, B.C.

about half of the provincial seedling requirements. Some of these nurseries have been instrumental in the development of techniques recognized world wide for their ability to grow superior seedlings. By 1987 some 40 nurseries, including 11 Ministry of Forests nurseries, were producing seedlings for reforestation in British Columbia.

In September, 1987 the government announced plans to sell nine of the eleven Ministry nurseries to the private sector, as part of the government's efforts to reduce direct involvement in the production and delivery of goods and services. In the private sector, the nurseries will have greater incentives and opportunities to expand their markets and develop further efficiencies.

At this time seven of the nine nurseries put up for sale have been sold or are in the final negotiation stage for turnover on September 1, 1988. Studies are now being carried out for disposition of the remaining two nurseries offered for sale.

The Surrey Nursery and the Skimikin Nursery near Salmon Arm will continue to be operated by the Ministry of Forests. These will enable the Ministry to continue experimenting with new nursery techniques, and to grow seedlings for SBFEP and areas denuded by fire and pests.

So much for the forestry and nursery situation in British Columbia.

This is the fourth time that the Western Forest Nursery Council is meeting in British Columbia. Previous meetings were held in 1952, 1962, and 1976. The Forest Nursery Association of British Columbia was organized in the early 80's. Many members of each organization have been attending each others meetings.

Looking over the agendas of past meetings held in British Columbia we find some of the same topics being discussed at all of the previous meetings. Cold storage is a subject which continually keeps appearing. Another subject that keeps repeating at meetings such as this is seedling quality and field results. Seedling quality is a decisive factor for the success of a plantation. There should be no need for, nor can we afford the cost of going back to, or back over an area, because of failure due to seedling quality.

Early in the century, Gifford Pinchot, predicting that the planting of forest tree seedlings would grow in importance, urged that forestry professionals accept the challenge of reforestation by learning not only where to plant but where not to plant, and how to select the right trees. I would not like to suggest that forestry professionals have not been doing that for some time, but let us say that they are starting to do it better. They have had to take up the challenge, if for no other reason than to offset increased costs.

At the time, Pinchot's emphasis on the need for foresters to know how to select the right tree probably referred to species selection but now, with the variety of stock types that we can produce, the designation of stock type is an equally important part of any planting prescription. The nursery has traditionally been the scapegoat for plantation failures but we are now getting evidence of the importance of proper selection of the stock type to survival and its physiological conditioning as well as careful planting.

Morphological characteristics of the stock, its height, root collar diameter, top/root ratio, root system, can largely be determined by the cultural practices at the nursery. That is how we have defined stock quality to date. Is it unfair to say that we have been content to ship out what our experience told us were nice looking tree seedlings? How often did we carry out the destructive sampling that is necessary if we are to be reasonably sure that those nice looking seedlings are not dead.

We know now that it is the seedling's potential for achieving a satisfactory growth rate that will determine the success or failure of plantations and it is not possible to make that judgement just from the appearance of the stock.

Besides destructive sampling to check on the quality of stock classified by its morphological characteristics, if we are to be able to satisfy the requirements of the foresters as they become more specific in their prescriptions, we will have to develop a better understanding of seedling physiological processes, particularly the induction of dormancy and the factors controlling the root regeneration process. Most nurseries today use cold storage units. This is a useful tool for balancing nursery workloads and is essential with the large nursery operations that have developed to secure the benefits of mechanization. To be used effectively however, we will have to be able to induce specific seedling physiological states prior to cold storage, such as root regeneration potential, and we have to be able to maintain physiological vigour during the storage process. There is still a lot of work to be done by the tree physiologists before we can feel secure.

We must be able to define quality standards on both a morphological and physiological basis.

The changes in the technology and economics of forest nursery operation and seedling production over the past decade exceed that of any previous period, and the pace of change appears to be accelerating.

Meetings such as this provide the opportunity for people from different regions to come together, to compare experiences and solutions of similar problems, to exchange information and ideas, and to consider new concepts.

In closing I would like to emphasize that your contributions as nurserymen are key to the future of forest productivity. Through application of your skills and dedication to the task of producing quality seedlings, coupled with tree improvement programs, and the tools of the silviculturist, we can expect the future forest resource to become increasingly productive on those areas that are intensively managed for timber production. In so doing, we can offset the inevitable loss of parts of the commercial forest land base to wilderness, environmental restrictions, urbanization, etc., and thereby fulfill society's increasing demand for the full range of forest resources.

Dormancy and Vigour of Tree Seeds[1]

C.L. Leadem[2]

Abstract. This paper discusses tree seed dormancy and vigour with specific references to the true firs (Abies). The benefits of a modified stratification method--the stratification-redry technique--are outlined. Physiological measurements are described with some examples of how they may be applied to assess seed vigour. Especially promising for the development of seed vigour indexes are low temperature stress tests, germination rates, seed respiration, and seed reserve levels. These may soon be employed as management tools to aid nurserymen to monitor the deterioration of seeds in storage, to assess the effectiveness of dormancy release treatments, and to predict seed performance in the nursery.

TREE SEED DORMANCY

As nurserymen, you probably recognize that the dormancy of tree seeds can be a major impediment to seedling production. Simply put, if seeds do not germinate, there will be no seedlings. Seed dormancy may be defined as:

"The inability of seeds, due to a mechanical or physiological block, to germinate even when placed under favourable conditions for germination."

In this context, the mechanical block is most often the seedcoat, whereas physiological blocks are generally biochemical. Most tree seeds are dormant, and therefore require special treatment before they will germinate. The most effective dormancy-breaking treatment for many tree seeds is the chilling of moist seeds at 2°C, otherwise known as stratification. A modified method of stratification, the stratification-redry technique (Danielson and Tanaka 1978, Edwards 1986), has been shown to be effective for very dormant seeds such as amabilis fir (Abies amabilis Edwards 1980a, 1981; Leadem 1986). In the past year, the stratification-redry procedure has also been successful in overcoming the dormancy of subalpine fir (Abies lasiocarpa) seeds (Leadem 1988).

The efficacy of the stratification-redry treatment was demonstrated in an experiment in which three different seed sources of A. lasiocarpa received 10 stratification treatments (table 1). In the first 6 treatments, moisture was not controlled during stratification. Seeds were imbibed for 48 h, and moisture content (m.c.) remained about 45% during the entire chilling period.

TABLE 1. STRATIFICATION TREATMENTS @ 2°C

No. Weeks	Wks @ 45% mc	Wks @ 35% mc	Total
1.	*	*	*
2.	4	-	4
3.	8	-	8
4.	12	-	12
5.	12	-	16
6.	24	-	24
	Stratification-redry treatments		
7.	4	4	8
8.	4	8	12
9. **	4	12	16
10.	4	20	24

* Seeds were imbibed for 48 h, but received no chilling.
** Standard stratification-redry procedure.

In the remaining 4 treatments, seed moisture was reduced to 35% m.c. for part of the stratification period. The stratification-redry procedure (Treatment 9, table 1) was the standard on which all moisture-control treatments

1 This paper was presented to the Combined Western Forestry Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association Meeting; 1988 August 8-11, Vernon, British Columbia.

2 Carole Leadem is a Plant Physiologist with the British Columbia Ministry of Forests Research Laboratory, 1320 Glyn Rd., Victoria, B.C., Canada V8Z 3A6

were patterned. In treatment 9 seeds were soaked for 48 h and stratified at 2°C for 4 weeks at 45 % m.c. Seeds were then dried to 35% m.c. and stratified for an additional 12 weeks. In the remaining treatments (7, 8, and 10), the number of weeks of moisture control are longer or shorter than in treatment 9.

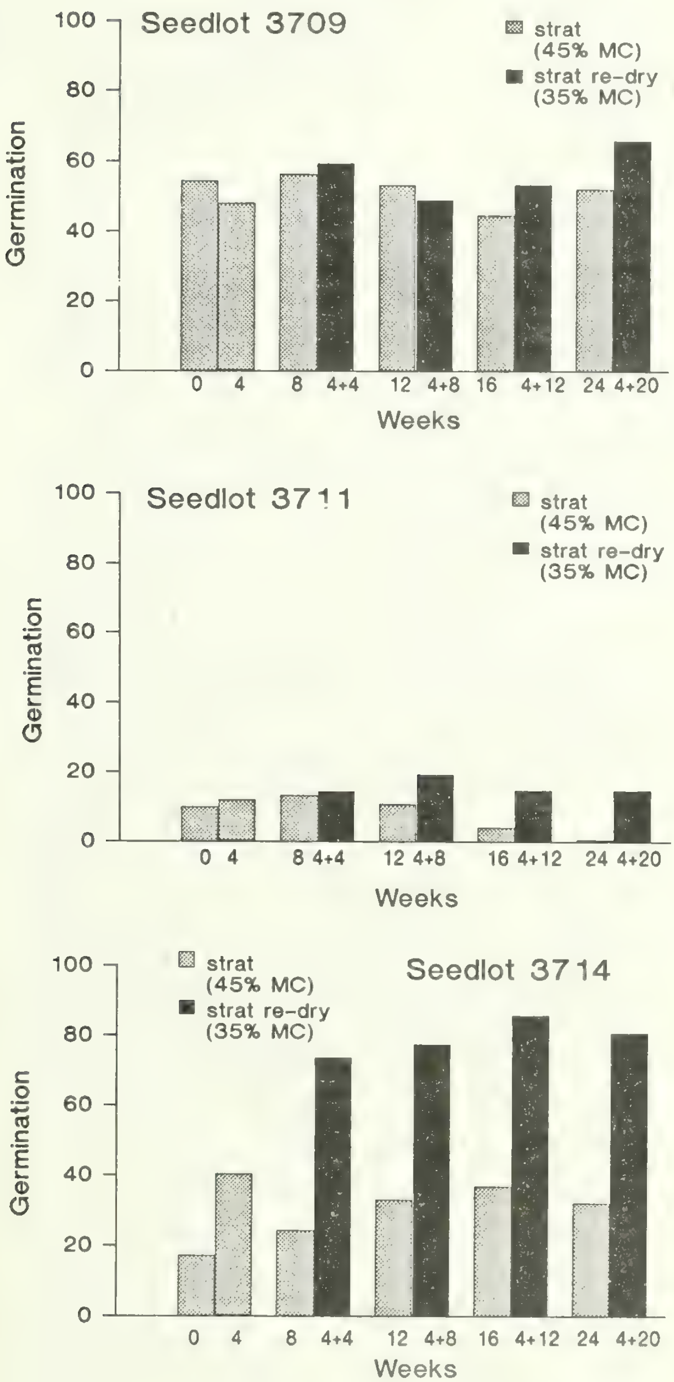

FIGURE 1. Germination of three Abies lasiocarpa seed sources to duration and stratification treatment with and without moisture control.

Germination tests of treated seeds were conducted by incubating the seeds under a daily alternating 30°C/20°C for 4 weeks (ISTA 1985). Eight hours of light were given during the high temperature period.

The responses of three A. lasiocarpa seed sources to stratification with and without moisture control are shown in figure 1. Lot 3709 exhibited the response of a nondormant seed source. Seeds germinated about 55% with no chilling, and none of the stratification treatments appeared to substantially increase germination above that of unstratified seeds. Although moisture control during stratification did not increase germination, the stratification-redry treatments were not detrimental to the germination of this nondormant lot. This is an important consideration in any nursery situation where efficient management is essential. Because the stratification-redry procedure enhances the performance of dormant seed sources but does not adversely affect nondormant seeds, only a single method is necessary to prepare seeds for sowing.

Seedlot 3711 consisted of poor quality seeds that did not respond very well to any of the treatments. This behaviour is characteristic of seeds that have been harvested prematurely or improperly handled in the field. These seeds do not germinate well, and deteriorate rapidly in storage (Edwards 1980). The quality of such seeds cannot be improved, regardless of treatment, and the best solution is usually to dispose of the lot.

In seedlot 3714, only 18% germination was achieved with unchilled seeds, but 4 weeks stratification substantially increased germination. This definite response to stratification is typical of dormant seed sources. Moisture control (i.e., reducing seed m.c. to 35%) during stratification had a major effect on germination of seedlot 3714. All the stratification-redry treatments (4 + 4, 8, 10 or 12 wks) significantly improved germination compared to that of seeds stratified for the same length of time without moisture control. The maximum response was 86% germination, observed in seeds which received treatment 9 (4 + 12 weeks). Seeds with no moisture control, and stratified for the same length of time, germinated only 37%.

Radicle emergence is generally taken as evidence of the breaking of dormancy, but more than just radicle emergence is necessary to demonstrate that dormancy requirements have been satisfied. Dormancy release is, in actuality, a composite of a number of qualities which enhance seed performance. In this regard, the stratification redry treatment effectively breaks dormancy of true firs (Abies), and also has been shown to enhance a number of qualities not ordinarily associated with the breaking of dormancy. Abies seeds are often susceptible to mold (Leadem 1986) and are poorly geotrophic. When given stratification-redry treatment,

however, the seeds not only germinate more rapidly and exhibit less fungal contamination, but the radicles are more likely to grow directly down into the substrate (unpublished data).

To date, the stratification-redry treatment has been found to be effective for releasing dormancy of Abies amabilis (Pacific silver fir); Abies grandis (grand fir); Abies lasiocarpa (subalpine fir); and Abies procera (noble fir) (Edwards 1981, 1982; Tanaka and Edwards 1986; Leadem 1986, 1988). Unfortunately, the use of stratification-redry on other species has been limited (Danielson and Tanaka 1978).

TREE SEED VIGOUR

It is generally acknowledged that seed vigour declines more rapidly than germination (Heydecker 1969). Accordingly, vigour tests have been employed as more sensitive indicators of deterioration and other qualities not as easily detected in germination tests. While several definitions of seed vigour have been proposed (Assoc. Off. Seed Anal. 1983), the following working definition is preferred:

"Seed vigour is that property which enables seeds to germinate quickly under a wide range of conditions, and endows germinants with the ability to establish quickly and resist disease."

This definition of vigour emphasizes the broader, more practical aspects of biological function as it relates to the health and performance of young germinants in the nursery. The period of early germination and emergence is critical to successful nursery production. Germinants which are endowed with those qualities referred to as vigour are better able to overcome the hazards inherent in the susceptible early emergence phase, and thus are more likely to become successfully established as healthy, free-growing seedlings.

Measurement of seed vigour

Although most nurserymen intuitively recognize vigour in seeds, the concept of vigour has been difficult to express quantitatively. The inability to quantify vigour has been a major obstacle to widespread acceptance of the seed vigour concept. However, some examples of previous attempts to quantify seed vigour are given in table 2. Germination value (G.V.) is a well-known measure devised by Czabator (1962) in which total germination and the speed of germination are combined into a single value. The G.V. index has only had limited use, however, because standard values must be empirically determined for each species. Germination value is expressed as a single value without units, and thus is also difficult to relate to other measures of germination performance.

TABLE 2. SOME INDEXES OF SEED VIGOUR

Index	Description
Germination value	Speed X total germination (Czabator 1962)
Stress tests	Temperature extremes (AOSA 1983)
Growth models	Mathematical expression (Tipton 1984)
Respiration	Biological function Carver and Matthews 1975)
Seed Reserves	Storage protein, lipids

Several seed vigour indexes, however, may have potential for testing tree seeds. Stress tests, usually conducted under high or low temperatures, have been widely used to test the vigour of agricultural species (AOSA 1983), and could be extended to tree seeds. Other examples of measures used to assess seed vigour are growth models (Tipton 1984), seed respiration (Carver and Matthews 1975) and seed reserves. Forest tree seed vigour based on low temperature stress tests, growth models, respiration, and seed storage products are considered more fully in the following sections.

Low temperature stress tests

Standard conditions have been prescribed for testing the germination of tree seeds (AOSA 1978, ISTA 1985). Although standard tests are essential when making comparisons between several seed lots, and between laboratories, the results of such tests may not be relevant to the nursery situation, because tests conducted under optimum conditions do not necessarily reflect how seeds will perform under less than optimal circumstances in the nursery.

Another consideration is that the benefits of seed treatments may not be apparent when comparisons are made under optimal conditions. Nursery tests conducted on Abies procera (Rehd.) by Y. Tanaka (personal communication, 1982) showed little difference between the stratification-redry technique and 2 months stratification when seeds were sown under warm conditions, but during cold, wet conditions, seeds that received the redry treatment germinated significantly better. Data obtained for Abies amabilis incubated under low temperatures (15°C/10°C) also illustrates that tests conducted under stress conditions may better indicate the efficacy of different stratification treatments in situations that are more similar to those encountered in the nursery (fig. 2). Similar data were obtained by Davidson et al. (1985) who also incubated Abies seeds under low temperatures.

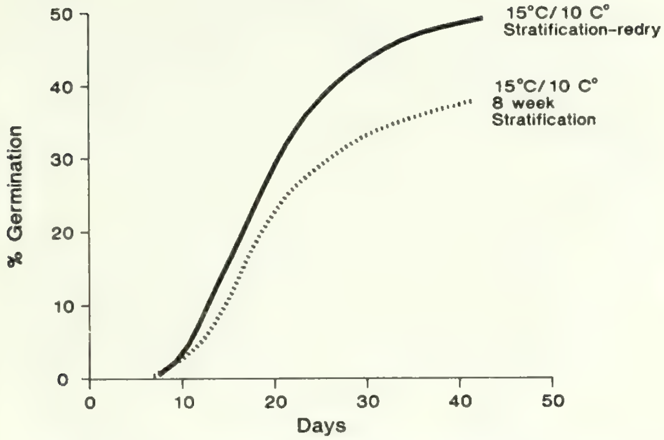

FIGURE 2. Germination of Abies amabilis seeds at low temperatures after receiving different stratification treatments

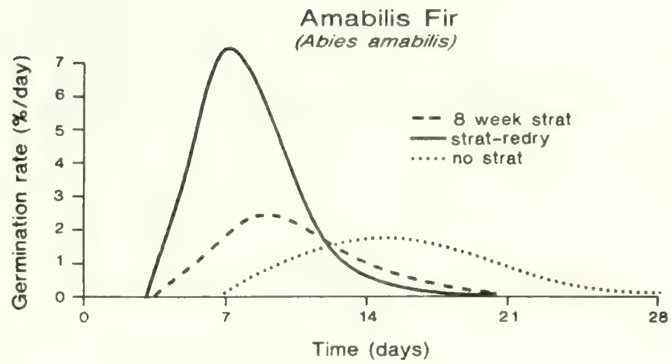

FIGURE 3. Germination rate curves of Abies amabilis seeds which received different stratification treatments.

Growth Model Vigour Index

Mathematical expressions of growth known as growth models, can be employed to transform standard germination curves into a more useful form (Tipton 1984). Growth models use the same basic data used to generate standard germination curves, but the data are mathematically transformed to create other expressions of biological performance, such as germination rate curves. Such curves graphically depict growth characteristics that are not otherwise detectable, and thus may be more sensitive indicators of seed performance (fig. 3).

The benefits of the stratification-redry treatment, for example, are readily seen if germination data is transformed and graphically expressed in the form of germination rate curves. After examining the curve characteristics of the three treatments, it is apparent that seeds given stratification-redry treatment begin germination earlier, that more germinants emerge each day, and that the germination is completed within a shorter period. By this means it is possible to describe those desirable, although generally subjective, attributes which are collectively known as vigour (table 3).

TABLE 3. CHARACTERISTICS OF VIGOUROUS SEEDS

Vigourous seeds have the ability to:

- germinate under a wide range of temperatures
- resist disease
- germinate rapidly
- establish quickly
- function with greater physiological efficiency

Levels of Seed Reserves

Since the germinating embryos are solely dependent upon seed reserves, the absolute amounts of reserves stored in the seeds might be expected to directly affect seed vigour. Conifer seeds store reserves mostly in form of fats and protein (Kozlowski 1971, Leadem 1987). With this thought in mind, the relationship between storage proteins and the seed quality was examined in Abies lasiocarpa to see if this could be developed into a useful indicator of seed vigour.

Seeds were sampled from three seed sources at various times during stratification. Seedcoats were removed and fresh weights were measured prior to grinding each sample in 0.05 M potassium phosphate buffer, pH 7.0. Ground samples were then frozen at -20°C until protein extractions, based on procedures previously described by Gifford et al. (1982), were performed. Protein content was assayed by the Lowry method (Lowry et al. 1951).

Germination tests were conducted at 30°C/20°C with 8 h light. Significant differences between protein concentrations and germination percent were tested using analysis of variance. The results are given in table 4.

For any one seedlot, protein values did not vary significantly during stratification. Significant differences in the total seed protein levels between the three seedlots were found ($F=23.39$, $P<0.001$). A direct relationship could also be seen between total protein and germination percentage; the greater the total protein values, the better the seeds germinated. These results are preliminary, but are encouraging to the extent that a vigour index based on protein reserves might exist. Ultimately, it may be possible to find specific proteins whose presence is highly correlated with seed vigour and quality, but further studies are necessary to determine the identity of the candidate proteins.

TABLE 4. TOTAL PROTEIN

Seedlot	Total Protein (mg /10 seeds)	Germination (%) (4wk @45% + 12wk@35%)
3714	26.16 a	86.0 a
3709	23.98 b	53.3 b
3711	18.56 c	14.7 c

Within each column, means with the same letter are not significantly different at p = 0.05 based on Duncan's Multiple Range Test.

Respiration as a Vigour Index

Seeds generate energy for growth and development by respiring stored reserves. The rate at which seeds use their reserves is an indication of their physiological efficiency, and, potentially, also a measure of vigour.

Seed respiration is easily monitored with an apparatus known as the Clark oxygen electrode (Yellow Spring Instruments, Yellow Springs, Ohio) (Murphy and Noland 1982). Seeds are placed in the cuvette with a phosphate buffer to retain peak physiological activity. Temperature is maintained at 30^{o}C with the constant temperature water bath assembly.

Using the Clark oxygen electrode, the respiration of A. lasiocarpa seeds was monitored while applying the stratification treatments described in table 1. The primary objective of the experiment was to study the effects of stratification, both with and without moisture control, on seed respiration and germination.

Respiration of seeds of seedlot 3714, which had been previously demonstrated to be a good quality, but dormant lot, was low when seed moisture was controlled throughout the chilling period (stratification-redry treatment)(fig. 4). For seeds stratified at high moisture levels (> 45% m.c.), respiration rates were also initially low, but they increased exponentially after 16 weeks. In seeds stratified with moisture control (35% m.c.), respiration increased only slightly with treatments longer than 16 weeks.

A different respiratory pattern was observed in the poor germinating seeds of lot 3711. Although respiration rates were relatively low for the first 4 weeks, seeds stratified at high moisture contents exhibited excessive respiration when the treatment continued past 4 weeks. By comparison, respiration in seeds with moisture control remained comparatively constant ana increased relatively little during stratification.

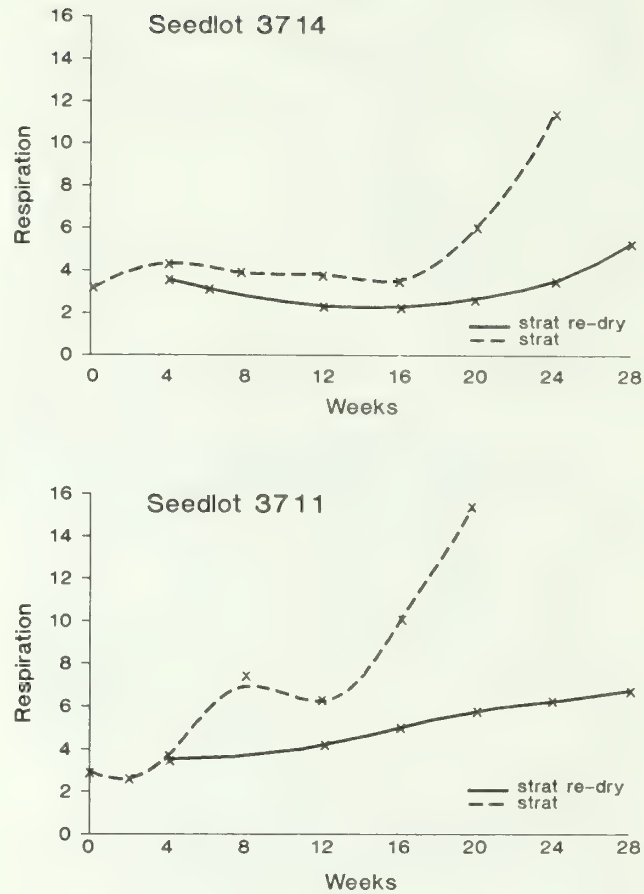

FIGURE 4. Changes in the respiration rates of Abies lasiocarpa seeds during stratification. Seeds were stratified at 2^{o}C with or without moisture control.

It should be cautioned that respiration measured at 30^{o}C does not necessarily reflect how seeds respond during stratification at 2^{o}C, and also that, to date, few comparisons have been made. However, the data suggest a relationship between respiration and seed performance which may partly explain how the statification-redry treatment improves seed performance. Dormant species such as the true firs require long periods stratification to achieve optimal performance (Leadem 1986). The data in this study indicate that if seed moisture is kept at high levels, respiration tends to rise with increasing time of chilling at 2^{o}C. Increased respiration during stratification may have significant impacts upon subsequent seed performance, for if reserves are respired during stratification, they will not be available for use during germination. If, on the other hand, stored products are slowly respired during stratification, more energy supplies will be available for the critical emergence and establishment period.

This study also indicates that changes in seed respiration may reflect changes in dormancy status. If respiration rates in figure 4 are compared to germination data in figure 1, it can be seen that the rise in respiration after 16 weeks is coincident with the length of stratification necessary to overcome the dormancy of the seedlot. This rise in respiration may be related to the breaking of seed dormancy.

The ability to identify when the breaking of dormancy occurs could prove to be valuable in assessing the physiological status of seeds. The usual method of determining stratification requirements is to subject seeds to a series of chilling times, and then germinate the seeds. The use of seed respiration as an alternate method of assessing performance would greatly simplify the search for optimal stratification treatments, since with the Clark oxygen electrode, seed respiration can be measured in 5 minutes as opposed to the 3-4 weeks required for a germination test.

CONCLUSION

Seed vigour has been shown to be related to germination rate, seed protein levels, and seed respiration, each of which have potential for the development of quantifiable indexes of seed vigour. Some day, we may have a simple, one-step vigour test which, by monitoring essential biological processes, will enable us to use our seed resources more efficiently. Physiological measurements such as seed respiration and storage protein may provide some valuable new technology for predicting seed performance, and to a time when nursery managers can truly say that "What you see, is what you get".

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Province of British Columbia Ministry of Forests Seed Centre[1]

R. Bowden-Green[2]

Abstract. The purpose of this poster is to outline the Ministry of Forests Seed Centre's services and facilities. We now offer our services on a fee for service basis and indicate the time lines required, procedures to follow and forms to use.

LOCATION

The Seed Centre, Ministry of Forests is located at 18793-32nd Avenue, Surrey, B.C.

CONE PROCESSING

The Seed Centre can store more than 6500 sacks (2600 hl.) of cones in storage racks.

An additional 1100 hectolitres of cones can be stored on conditioning trays in a temperature controlled environment.

The natural gas fired, tray-style kiln equipped with a programmable controller can process up to 100 hl. of cones per day.

A Cone Collector's Report form (F.S. 721 or 721-A) plus a Cone-Seed Services form are required to initiate the processing of cones at the Seed Centre.

SEED PROCESSING

Seed processing is accomplished using a modern on-line system.

Seed is processed to remove wings, debris and empty seed.

The product of processing is 98 to 100% pure seed which is 100% potentially viable.

SEED REGISTRATION

Seed destined for crown land must be registered.

The Tree Seed Register and Inventory System provides reports on seed information and balance in store.

SEED TESTING

A representative sample from each seedlot is tested.

The seedlot quality in storage is monitored including periodic retesting.

SEED WITHDRAWAL SERVICES

Seed withdrawal is achieved via submission of a Sowing Request System form or a Seed Sale and Withdrawal form.

Sowing Request System provides calculations and reports.

SEED WITHDRAWAL TIME LINE

Working days required from time of request to seed being withdrawn and shipped:

Period	Sowing Request	Seed Sale/ Withdrawal
Nov. 1-Dec. 31	25 workdays	25+ workdays
Jan. 1-Apr. 30	20 workdays	25+ workdays
May 1 -Oct. 31	6 workdays	6 workdays

SEED STRATIFICATION TIME REQUIRED

Stratification (days)	Species
21	(Spruce (Douglas-fir (Western larch
28	(Western hemlock (Mountain hemlock (Lodgepole pine (Ponderosa pine (Grand fir
84	(Subalpine fir (Amabalis fir (Yellow cedar (White pine

1 Poster presented at the Combined Meeting of the Western Forest Nursery Associations, Aug. 8-11, 1988, Vernon, British Columbia.

2 R. Bowden-Green is with the British Columbia Ministry of Forests, Surrey, British Columbia.

Macro and Micronutrient Programmes in B.C. Bareroot Nurseries[1]

John W. Maxwell[2]

Abstract.--In 1986 an intensive foliar analysis programme was introduced, subsequently, boron, copper, iron and zinc were often found to be low or deficient during the growing season and lift. The programme combined the introduction of micronutrient soil amendments and foliar sprays and has significantly improved stock quality.

INTRODUCTION

In British Columbia, there are eight bareroot nurseries; six ministry, one company and one private, located in various climatic zones. Over the years, the nutrient programmes and stock standards have changed quite dramatically with increased demands for larger and more suitable stock types. In 1986, frequent foliar nutrient analysis programmes were introduced. This has helped in modifying fertilizer schedules to suit the different stock standards.

SOIL NUTRIENT LEVELS

Soil types on the nurseries vary from coarse sands to clay loams. Fortunately, most of the nurseries with the heavier soils are no longer in bareroot production. The ministry bareroot nurseries are on a three year crop rotation, with two years of crops and one of fallow. No green manure or cover crops are grown, which results in good disease control but is a poor soil management practice. As a result, organic matter levels must be maintained by adding peat prior to seeding and transplanting. The addition of sawdust in the fall, to reduce frost heaving, also helps. Although these practices maintain the level of organic matter and keeps the cation exchange capacity (O.M.) (C.E.C.) at a satisfactory level, they do not improve the soil tilth in the same way that humus does.

[1] Paper presented at the Combined Meeting of the Western Forest Nursery Associations, Aug. 8-11, 1988, Vernon, British Columbia.

[2] John Maxwell is a retired Bareroot Extension Specialist, British Columbia Ministry of Forests and Lands, White Rock, British Columbia.

Soil analysis was only done during the summer of the fallow year. The nutrient levels that were used (table 1) were a modification of those established for Douglas fir by van de Driesche (1969), and further adjustments were made for the various nurseries as and when required.

Table 1.--1988 Soil nutrient levels[1] used on B.C. Forest Service nurseries.

ph	% O.M.	% N Kjeldahl	P pm Bray 1	K m.e.q./100g	Ca m.e.q./100g	Mg dry	CEC soil
5.2 -5.8	3-8	0.20 -0.25	100 -250	0.20 -0.30	5.0 -8.0	<1.4	15 -20

[1]These levels were required prior to sowing or transplanting.

Macronutrient plant analysis was only carried out at the end of the growing season on specific 1-0 and the occasional 2-0 seedlots. The 2-0 fertilizer programmes were determined using the mineral nutrient ratios for seedling tissue established by Ingestad (1979).

The pH was maintained at a high level for forest nurseries, because the fertilizers used tended to be acidic. During the growing season, a pH of 4.4 was often found in the soils, which does effect the availability of some nutrients.

The nitrogen (N) levels, although of major importance, were disregarded when preparing the fertilizer programmes because of the numerous processes which affect N in the soils. This results in too much variation over short periods. Ammonium sulphate was the main N source, with ammonium nitrate being applied occasionally on 2-0 and transplants. The latter

caused a considerable amount of damping off in 1-0 stock.

Phosphorus (P) was maintained at a very high level because a slight reduction at the time of seeding considerably reduced the size of the 1-0 and 2-0 stock. There were also indications that under certain conditions high P was essential for the success of some plug transplants. These levels were of concern, as they do reduce the availability of zinc (Zn), copper (Cu) and iron (Fe) (Chapman 1966). Superphosphate, triple superphosphate, diammonium phosphate and monoammonium phosphate were the P fertilizers used. The amount of monoammonium phosphate applied prior to sowing was reduced by injecting or banding it below the seed drill, which also resulted in a considerably improved 1-0 stock quality.

Despite potassium (K) levels being satisfactory or high in some nursery soils, there was often some difficulty maintaining acceptable levels in the seedlings and transplants (van den Driessche 1977). This became more pronounced during root wrenching and undercutting. It appears that these two cultural practices, combined with frequent irrigation, reduce the plants' ability to take up K. This may be due to the soil pH, the reduced root area in contact with the soil, root form (Mengel and Kirby 1982) and leaching (Duryea and Landis 1984). Frequent applications of potassium sulphate are now being made at these stages of root culture. High K soil levels also tend to depress the uptake of magnesium (Mg).

Though calcium (Ca) is essential for good root and apical meristem development, there was always some concern about the effect it had on the soil pH. When necessary, Ca was applied as either limestone or dolomite, and the rates used depended on the pH.

In spite of applications of dolomite, potassium-magnesium sulphate and magnesium sulphate, magnesium tended to be low. High K and Ca soil levels may induce Mg deficiency symptoms. The increase in the K supply may reduce the Mg content in the foliage. It does not, however, affect the levels in the roots or fruit to the same extent, because high K promotes the translocation of Mg towards fruits and storage tissues (Mengel and Kirby 1982). The calcium-magnesium and potassium-magnesium relationships are very important nutrient interactions in the production of seedlings.

Sulphur (S) was not a problem in bareroot production because of the large amounts applied in the fertilizers.

All the macronutrients were broadcast and worked into the soil prior to bed shaping. Some P was also injected or banded under the seed drill at the time of sowing, in the spring. Top dressings of the fertilizers were carried out on all stock types when necessary during the spring, summer and fall.

FOLIAR ANALYSIS FOR MACRO AND MICRONUTRIENTS

Until recently, little attention was paid to the micronutrients because the analysis service was not readily available. Over the years, visual identification of deficiencies was made and later confirmed by an analysis; but there was no micronutrient analysis programme in place. The importance of complete foliar analysis programmes in forest nurseries are demonstrated by the example of boron (B) increasing the resistance of forest plants to frost, drought and disease (Baule and Fricker 1970).

In 1986, a new programme was established allowing the nurseries to carry out foliar analysis for macro and micronutrients during the growing season. This was a tremendous step forward, although acceptable levels had not yet been clearly defined. The nutrient requirements and levels in plants vary with the species (Ballard and Carter 1986) and type of culture (Landis 1985). The levels that are used for bareroot are not necessarily suitable for containers. This is because the nutrient availability varies considerably between mineral soils and organic mediums, and is also affected by soil temperatures. There were difficulties in deciding on acceptable levels for all species and stock types, because they vary throughout the plant at different stages of growth. The levels used are based on trials conducted at the test nursery near Victoria, and research carried out to determine the best seedlings based on morphological and nutritional standards. The currently recommended nutrient levels (table 2) are used for all species and stock types.

Table 2.-- 1988 Nutrient Levels

Element	Target %	Accepted Range %
Nitrogen	2.0	1.50-3.50
Phosphorus	0.25	0.20-0.40
Potassium	1.0	0.80-2.00
Calcium	0.35	0.20-1.00
Magnesium	0.15	0.12-0.30
Sulphur	10% of N level	Minimum 0.15
	ppm	ppm
Iron	100	80-600
Copper	8	4-20
Zinc	30	25-80
Manganese	100	80 and up
Boron	30	20-50

When necessary, large macronutrient applications were made during the late fall and early spring. In order to accommodate various climatic conditions, the late fall top dressings were carried out at just about freeze up in the interior. The early spring ones were carried out in late February or early March at the coast (Mengel and Kirby 1982). Micronutrients were sometimes applied as soil amendments with the macronutrients.

During the growing season, foliar applications of P, K, Ca, and Mg, and micronutrients were made when necessary. The rates that were used (table 3) are the lowest ones that have been used successfully in the vegetable industry (Knott 1966) and the bareroot forest nurseries in British Columbia.

Table 3.-- Nutrient Application Rates

Nutrient	Material and approx. analysis	Soil Applic. (kg/ha)	Foliar Applic. (kg/1100 L water/ha)
Boron	Solubor ($Ns_2B_4O_75H_2O$) 20.5% B.	5	1
Calcium	Limestone, dolomite, gypsum, superphosphate	-	-
	Calcium nitrate ($Ca[NO_3]_2,2H_2$) 20% Ca.	-	5-10
Copper	Copper sulphate ($CuSO_4,5H_2O$) 25.5% Cu.	25	2
Iron	Ferrous sulphate ($FeSO_4,7H_2O$) 20% Fe.	10	2
Magnesium	Dolomite 20-45% Mg.	-	-
	Magnesium sulphate ($MgSO_4,7H_2O$) 9.8% Mg.	150-200	10-15
Manganese	Manganese sulphate ($MnSO_4,4H_2O$) 24.6% Mn.	20	20
Sulphur	Agricultural Sulphur	100-200	-
	Ammonium Sulphur	-	-
	Potassium	-	-
	sulphate and	-	-
	superphosphate.	-	-
Zinc	Zinc sulphate ($ZnSO_4,7H_2O$) 22.7% Zn.	10	2

Nutrient deficiency symptoms were considerably reduced following the implementation of the foliar analysis programme. Samples were collected in the early spring and during the growing seasons at 4-6 week intervals until the fall. During that period, some variability existed due to the translocation of nutrients to various organs; however, appropriate adjustments were usually made during the current growing season.

Enough top material was collected to provide at least 5 grams dried weight of small seedlings or needles. The tissue was air or oven dried at 60° C prior to shipping to the laboratory, and the results were usually available within three or four days. This allowed remedial action to be taken immediately.

Analysis indicated that P, K, Ca and Mg were sometimes low. While P tended to be deficient in 2-0 coastal Douglas fir and sometimes in lodgepole pine, 1.5-1.5 interior spruce and 2-0 coastal Douglas fir often suffered from K deficiency and occasionally there were problems at some nurseries with Ca and Mg.

Among micronutrients B, Cu, Fe, and Zn, were the main concerns. B and Zn deficiencies appeared to be involved in the multi bud and leader, rosette, and dominant bud failure in interior spruce (Ballard and Carter 1986). These problems were eliminated or considerably reduced following the introduction of the micronutrient analysis and spray programme. Normally, a single application was necessary, but sometimes additional treatments were required. In the past, many of these problems were blamed on stock type, weather and/or chemical damage.

Intensive production of bareroot is still dependent on sound management. This is done by using all available resources including foliar and soil analysis, because the climate, environment and other factors all have considerable effect on a crop.

CONCLUSION

In British Columbia, the bareroot nursery stock types have improved considerably in the past few years. One of the major reasons for this has been the approach to plant nutrition. The new plant analysis programme has helped to optimize the plant nutrient status of forest seedlings.

When necessary, the nutrient target levels for the various species and stock types will be updated so that the programme will achieve its potential.

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Nursery Practices, Seedling Sizes, and Field Performance[1]

William I. Stein[2]

Abstract.--Highlights are presented from a large cooperative study to determine the combined effects of nursery cultural practices on the initial size and subsequent field performance of 2+0 Douglas-fir seedlings. The study involved seven sources of stock produced in three different nurseries and field plantings made over 3 years on 28 sites in southwestern Oregon. Seedbed density had more effect on the size of seedlings produced and on subsequent 4-year field survival and growth than did variations in irrigation frequency or undercutting and wrenching.

INTRODUCTION

A large cooperative research endeavor to determine the combined effects of nursery cultural practices on the size and subsequent field performance of 2+0 Douglas-fir seedlings has been underway in southwestern Oregon for the last decade.[3] This short report provides nurserymen a preliminary synopsis of field results that, when fully analyzed, will be covered in one or more scientific articles.

OBJECTIVES

Nursery cultural practices used in the production of bareroot stock received renewed emphasis during the 1970's. Wrenching was given particular attention, but various studies were also made on the effects of seedbed density, undercutting, fertilization, and other practices. Much information was produced by these studies, but there remained important gaps in our understanding; namely, (1) There was conflicting evidence on the benefits of wrenching. (2) Most studies had measured the effects of varying a single practice at only one nursery. (3) The longer-term effects of nursery practices on seedling field performance were not known.

A multi-faceted study involving three nurseries, outplantings in 3 years, and subsequent field observations for 4 years was carried out to learn more about the combined effects of nursery practices. The first description of this study was reported at the Nursery Council's meeting in Eureka, California (Jaramillo 1978, Stein 1978), and completed results for one facet of the effort were reported at the Council's meeting in Coeur d'Alene, Idaho (Stein 1984, 1985).

METHODS

The general approach in this investigation was to subject Douglas-fir seedlings to different combinations of nursery cultural practices during their second year in the nursery, measure a sample of the seedlings produced, and subject other samples to greenhouse and outdoor performance tests. The key performance test involved planting rows of seedlings representing each treatment combination on contrasting forest sites. Over a 3-year period, trials were made with seedlings from seven seed sources grown in three nurseries and tested by identical methods.

In four trials, seedlings were produced in 18 combinations of three nursery practices--two moisture regimes, three levels of root disturbance, and three seedbed densities. In two additional trials, fertilization was also varied, and each nursery practice was applied at two levels--16 combinations. One trial had only nine treatment combinations--three levels of root disturbance and three seedbed densities.

[1] Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2] William I. Stein is a Principal Plant Ecologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oreg.

[3] Cooperating organizations included the Roseburg District, USDI Bureau of Land Management; D.L. Phipps Nursery, State of Oregon; Wind River and Humboldt Nurseries, Siskiyou National Forest, and the Pacific Northwest Research Station, USDA Forest Service. Financial support for this research was provided by the USDI Bureau of Land Management and USDA Forest Service under the auspices of the Southwest Oregon Forestry Intensified Research (FIR) Program.

In each trial, treatment combinations were replicated three times on stock of the same seed source--in most instances, replications were made in seedbeds adjacent to each other. Every treatment combination was randomly assigned to a plot in each bed. Either in the fall of the first season or early spring of the second, all plots were thinned as specified to 10, 15, or 30 seedlings per square foot (108, 161, or 323/sq. m). Later in the spring, one-third of the plots were undercut at 6 inches (15 cm). Another third of the plots, as designated beforehand, was undercut and wrenched at 8-inch (20-cm) depth when seedlings were 8 inches (20 cm) tall, with wrenching repeated at 3-week intervals until September. The remaining third of the plots received the same undercut and wrenching treatment and, in addition, was vertically root-pruned on two sides every 6 weeks. In their second growing season, seedlings were irrigated often enough before June 15 to keep their moisture stress at dawn below 5 bars. In the following 2 months, seedlings in half the plots were allowed to reach stresses up to 12 bars before rewatering. In late summer and autumn, all seedlings were allowed to reach the higher stresses before rewatering.

Samples of seedlings from all treatments were collected in fall and winter for measurement of size and tests of performance, but only those lifted in winter were outplanted on forest sites. To achieve equal sorting of all treatments, only damaged seedlings and obvious runts were culled. Thus, some small-diameter or short seedlings that normally would be culled were included in the sets of sample seedlings.

Seedlings of a single seed source were planted on four clearcuts appropriate in location and elevation for the source. Planting sites were chosen to represent contrasting conditions--generally moderate to severe reforestation situations (fig. 1). Three blocks of test trees were planted on each site; each block contained one row of each treatment. Rows contained 20 trees each. Thus, each treatment combination was represented by 240 trees per seed source--12 rows in three replications at four locations. Trees planted in the third year were protected by plastic mesh tubing. Most outplanting sites were on Bureau of Land Management lands both east and west of Roseburg, Oregon.

Survival and total height of outplanted seedlings were obtained after the first, second, and fourth growing seasons. Also, the size attributes at outplanting were measured for seedlings from all treatment combinations. For purposes of this broad overview, an average was calculated for each irrigation, wrenching, and density level tested on the individual seed source. Treatment averages from all seed sources with the same treatment combinations were then summed and overall averages calculated. Six of the seven seed sources included comparison of two moisture levels, but only five included three levels of root disturbance and seedbed density.

RESULTS

Seedling Size

Seedlings tested for field performance were generally of medium length, sturdy, and well-balanced. Top lengths of seedlings averaged 10.1 inches (25.7 cm), and means ranged from 8.0 to 12.8 inches (20.4 to 32.5 cm) among the seven

Figure 1.--Seedlings were planted on contrasting sites in geographic locations appropriate to the seed source. Sites included: (LEFT) a steep, unburned north slope at 2,800 feet (850 m) in the Cascade Mountains east of Sutherlin, Oregon, and (RIGHT) a freshly burned south slope reclaimed from evergreen brush at 1,700 feet (520 m) in the Siskiyou Mountains south of Riddle, Oregon.

seed sources. Stem diameters averaged 0.19 inches (4.9 mm), and source means ranged from 0.16 to 0.23 inches (4.0 to 5.9 mm). Total dry weights of seedlings averaged 7.4 gm, with source means ranging from 5.5 to 9.6 gm. Top-root ratios averaged 1.83 and ranged from 1.47 to 2.34 among the seed source means.

The combinations of cultural practices under which seedlings were produced influenced some of their physical attributes but had little influence on others. Additional irrigation produced seedlings that averaged 0.3 inch (0.8 cm) taller, the same diameter and weight, and slightly different in top-root ratio, 1.87 versus 1.80, than those irrigated with less frequency. Seedlings undercut and wrenched after reaching a specified target height averaged 0.4 inch (1.1 cm) taller than those undercut early in the season; their stem diameters averaged slightly less, however, 0.20 versus 0.21 inches (5.1 versus 5.3 mm). Average dry weight and top-root ratio were almost equal for seedlings subjected to undercutting, undercutting and wrenching, and undercutting and wrenching plus root pruning treatments.

Seedbed density had no effect on average top length of seedlings but influenced their average stem diameter and total dry weight. Among the seed sources tested at three densities, stem diameters averaged 0.23, 0.20, and 0.18 inches (5.7, 5.2, and 4.6 mm), respectively, for the least dense to the most dense seedbeds. Total dry weights averaged 9.2, 7.3, and 5.5 gm per seedling from the least dense to the most dense seedbeds, and top-root ratios were 1.73, 1.83, and 1.93.

Field Performance

Two-thirds of the seedlings planted in the field were alive at the end of 4 years. The average survival among the seven seed sources (and the different geographic areas they represented) ranged from 38 to 83 percent and among the 28 locations at which the seedlings were planted from 14 to 92 percent. Survival in midseason of the first year averaged 96 percent or more for all seed sources except one, demonstrating that healthy seedlings had been planted on all but the four locations receiving stock of this source. Midseason survival was 75 percent for the seed source affected by root rot in the nursery. This source also averaged the lowest survival by the fourth year (38 percent) and had the lowest average (14 percent) for any single field location. Low survival at another field location resulted from planting an area where grass and other competition was already established.

Variations in the cultural practices under which seedlings were produced had only minor influences on their field survival. Survival for seedlings produced under moderate moisture regimes averaged 4 percent higher than for those produced under abundant moisture regimes. Survival for seedlings that were only undercut averaged just 3 percent lower than those subjected to undercutting plus wrenching or wrenching and side pruning. Seedlings produced at the highest seedbed density averaged 6 percent lower survival than those produced at the lowest density.

Seedlings averaged 28.4 inches (72 cm) in total height 4 years after outplanting. As might be expected, there were large differences among sources (and the geographic areas they represented) in average total height--from 17.6 to 52.5 inches (45 to 133 cm). Among all 28 locations, average total height ranged from 11.7 to 63.9 inches (30 to 162 cm). There was as much as a two to one difference in total height among locations planted with seedlings of the same source. Heavy browsing by deer caused seedlings at one location to be substantially shorter than elsewhere.

Only the density at which seedlings were grown had a material effect on their total height in the field 4 years later. Average total height varied 0.4 inch (1 cm) or less for seedlings produced under the two moisture regimes or the three root disturbance treatments. Average total height was 1.8 inches (4.5 cm) greater for seedlings produced at the lowest seedbed density than for those produced at the highest density and intermediate for seedlings from medium density beds.

Stem diameters, measured at 12 inches (30 cm) above ground level, averaged nearly 0.4 inches (9.8 mm) 4 years after outplanting. There were large differences in average stem diameter among seed sources and the geographic areas they represented, ranging from 0.2 to 0.7 inches (5.6 to 18.4 mm). For individual locations, the range was even greater, from 0.15 to 0.88 inches (3.7 to 22.4 mm). Again, the cultural effect of seedbed density was more evident 4 years after outplanting than were the effects of moisture regime or level of root disturbance, but all treatment differences among average diameters were small, .04 inches (1 mm) or less.

DISCUSSION

The seedlings outplanted in this study varied substantially in size, but on the average, they met the quality standards considered desirable for Douglas-fir planting stock--top length over 8 inches (20 cm), stem diameter 0.12 inches (3 mm) or larger, and good balance between tops and roots. Top-root ratio was low, averaging 1.83 with a range of 1.31 to 2.43 among treatments. Wrenching regimes were timed to produce good-sized, balanced seedlings, and this objective was achieved. When outplanted, the primary physical differences among seedlings of different treatments were differences in stem diameter and weight attributable to the densities at which they were produced.

Four years after outplanting, differences in survival and growth of seedlings reflected

primarily the initial size effects attributable to seedbed density. Heavier seedlings, resulting from lower seedbed densities, tended to survive and grow better in the field. The effects reflect relatively small differences in density of the seedbeds--a target difference of 10, 15, and 30 seedlings per square foot (108, 161, or 323/sq. m) at the start of the second season. The lowest density at harvest was near 10 per square foot (108/sq. m) but actually closer to 25 than 30 per square foot (269 than 323/sq. m) at the highest density. Studies have shown that large seedlings do better than small seedlings on favorable sites, and within the limits of the seedling sizes tested, results of this study indicate that larger seedlings also tend to do better on sites where moisture stresses are moderate to severe.

Despite large differences in the climates and soils in which seedlings were produced and field tested, the same combinations of cultural practices had similar effects. This is an important finding for it improves the predictability of seedling performance--when seedlings treated the same way in different nurseries respond the same way, not necessarily in magnitude but in direction of the response. Among the range of cultural practices tested, evidence from this study indicates that seedbed density is a more critical determinant of seedling size and future performance than are more frequent watering or more root disturbance from wrenching.

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Effect of Paclobutrazol on Conifer Seedling Morphology and Field Performance[1]

W. Rietveld[2]

Abstract.--Paclobutrazol, an inhibitor of gibberellin biosynthesis, significantly reduced the growth of jack pine, red pine, and eastern larch bareroot nursery seedlings. Application in August prior to the final complete year in the nursery was more effective than application in April of the final complete year. In many cases, the higher concentrations of paclobutrazol (10-20 mg/plant) retarded root growth as well as shoot growth, and retarded first-year growth in the field. One treatment (red pine, 5 mg/tree, applied in April) resulted in a 20% reduction in seedling height, 33% increase in root dry weight, and 35% reduction in shoot:root ratio, without carryover effects to the field. Further work is needed to optimize the shoot and root growth responses to paclobutrazol and to control its persistence in the soil.

INTRODUCTION

Paclobutrazol[2] (PP333, ICI Americas, Goldsboro, NC) is a potent growth regulator of a broad range of angiosperms, including monocotyledons and dicotyledons, and herbaceous and woody species (Shearing and Batch, 1979, Quinlan, 1981, Williams and Edgerton 1983, DeJong and Doyle 1984, Wood 1984, Sterret 1985). An inhibitor of gibberellin biosynthesis (Hedden and Graebe 1985), paclobutrazol has been extensively studied in horticultural species because of its ability to retard vegetative growth while improving fruit set and yield. However, little work has been done on the effects of paclobutrazol on gymnosperms, particularly conifers. Wheeler (1987) reported that paclobutrazol significantly reduced the growth of container-grown Douglas-fir (Pseudotsuga menziesii Mirb. Franco) and loblolly pine (Pinus taeda L.) when applied as a soil drench to newly germinated seedlings, but did not affect growth when injected into 3- to 9-year old trees.

Paclobutrazol has several potentially important uses in forest tree nurseries. It (1) is an alternative to shoot pruning, (2) manipulates seedling size and proportions to meet specifications, (3) improves seedling adaptation to water stress by decreasing the shoot:root ratio, and (4) is a means to hold over unneeded stock an additional year. Realizing any of the benefits on this "wish list" depends on the effectiveness of paclobutrazol on a particular species, and on developing appropriate application rates and methods. This paper reports the results of a study of paclobutrazol applied to bareroot jack pine (Pinus banksiana Lamb.), red pine (Pinus resinosa Ait.), and eastern larch (Larix laricina (Du Roi) K. Koch) seedlings at different stages of growth.

METHODS

The study was conducted at the USDA Forest Service J.W. Toumey Forest Nursery at Watersmeet, MI. Jack pine was seedlot 0477, Nicolet National Forest, zone 4; red pine was seedlot 0009, Hiawatha National Forest, zone 6; and eastern larch was seedlot 0152, Ottawa National Forest, zone 5.

Six rates of paclobutrazol were applied to each species at two times in the cultural

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[2]Trade names are included for the information of the reader and do not constitute endorsement by the USDA Forest Service.

period (early versus late). Applications were made either in August prior to the final complete year in the nursery or in April of the final complete year. Figure 1 shows the treatment times. Existing beds of seedlings were used for the study. Each species and application time was a separate test. Plots were 30-cm (1-ft) sections of bed with 30-cm buffers between treatments and the three replications. Rates of paclobutrazol (50% wettable powder) applied were 0, 0.5, 1, 5, 10, and 20 mg active ingredient/seedling in 5 ml water. The total amount applied to each plot was based on average seedling density (100-125/lineal foot) for each species and bed. Solutions were applied to seedling foliage with a garden sprayer; the plots were isolated with panels during spraying. The beds were irrigated 24 hr after application to standardize uptake time. Thus, the treatments consisted of foliar plus soil application of paclobutrazol, as in normal practice.

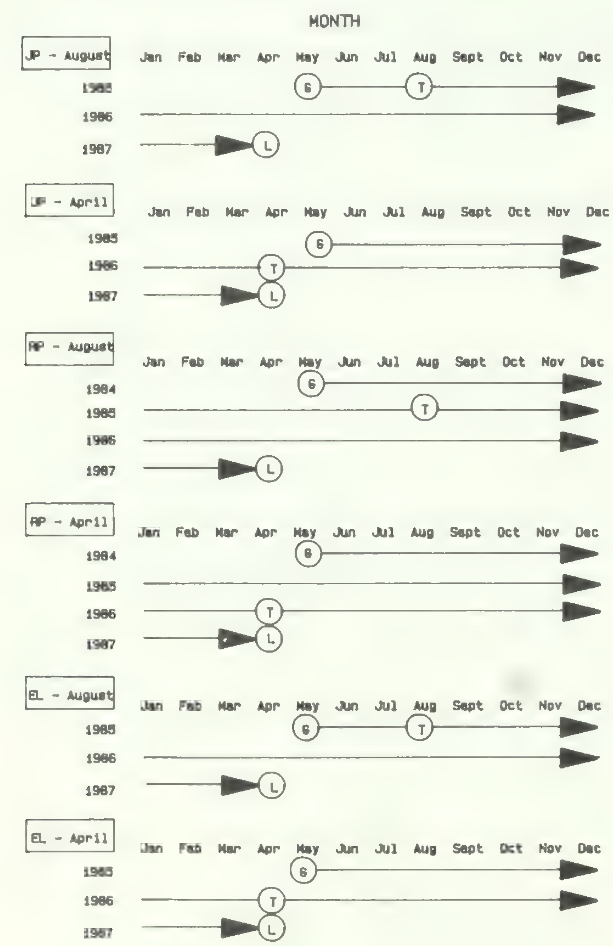

Figure 1.--Diagrams depicting growing periods and paclobutrazol application times for conifer nursery stock used in the study. Jack pine (JP) is normally grown to 2+0, red pine (RP) to 3+0, and eastern larch (EL) to 2+0. G = Germination, T = Treatment, and L = Lifting.

Seedling growth activity at time of application varied with age of plant. 2+0 and 3+0 jack pine and red pine had developing terminal buds at the August application, but 1+0 jack pine and 1+0 and 2+0 eastern larch were actively growing. The April application was made just prior to budburst for all species.

Seedlings were grown under normal nursery culture during the study. In April 1987 the seedlings were hand lifted and root pruned to a length of 20 cm. The three replications were combined, then a 15-seedling random sample was taken for morphology measurements, and a 30-seedling random sample was taken for a field test. Morphology measurements taken were: height, root collar caliper, root area index (using a Delta-T area meter), shoot dry weight, root dry weight, and shoot:root ratio (g/g). The field test consisted of three 10-seedling replications of each combination of species, application time, and chemical concentration planted under a rainshelter. Soil water potential was allowed to drop to -3.0 bars between irrigations. Survival, height growth, and caliper growth were measured at the end of one growing season.

Morphology data were analyzed for significant differences using one-way analysis of variance (ANOVA) and Tukey's multiple comparison test using a = 0.05. Field performance variables were analyzed using arcsin transformation, ANOVA, Tukey's test for survival data, analysis of covariance (using initial height and caliper as covariates), and Scheffe's multiple comparison test using a = 0.05 for height growth and caliper growth data.

RESULTS

Paclobutrazol treatments significantly affected all measures of growth and all species, primarily at the higher rates (table 1). In general: (1) order of sensitivity was eastern larch > jack pine > red pine; (2) application early in the culture period (August) was more effective than application late in the culture period (April); (3) the highest concentrations significantly reduced seedling size (height, caliper, shoot dry weight) and height growth in the field; and (4) effects on root growth were variable, but less than effects on shoot growth. Specific responses are presented by species and application time, focusing on significant differences from the control (0 mg/tree) treatment.

Jack pine--August application.--High concentrations of paclobutrazol effectively reduced overall seedling size. The 20 mg/tree concentration reduced height 54%, caliper 42%, shoot dry weight 48%, and root dry weight 46%. Height growth in the field test was also reduced 47%.

Jack pine--April application.--Paclobutrazol treatments only affected height growth in the field test, e.g. a 27% reduction by the 20 mg/tree concentration.

Red pine--August application.--The 20 mg/tree concentration reduced height 27%, caliper 23%, root area index 12%, and shoot dry weight 26%.

Red pine--April application.--The 5 mg/tree concentration reduced height 20%, increased root area index 51%, increased root dry weight 33%, and reduced shoot:root ratio 35%. Height growth in the field was reduced 69% by the 20 mg/tree concentration.

Eastern larch--August application.--The response was similar to jack pine--August, but to a greater degree. The 20 mg/tree concentration reduced height 65%, caliper 39%, shoot dry weight 59%, shoot:root ratio 25%, survival 41%, height growth 56%, and caliper growth 52%.

Eastern larch--April.--The two highest concentrations reduced seedling height, 17% for the 20 mg/tree concentration.

DISCUSSION

Paclobutrazol is effective in controlling seedling growth of coniferous species. The results of this study generally agree with Wheeler's (1987) in that young seedlings were most responsive. However, in this study root growth was inhibited nearly as much as shoot growth. The most notable (and usable) exception occurred in April-treated 3-year-old red pines at the 5 mg/tree rate (table 1). This retarded-shoot-growth/stimulated-root-growth response occurred in only one species and application time; therefore, its validity should be evaluated in further testing. Other investigators have also noted that paclobutrazol can either increase (Atkinson and Crisp 1983) or decrease (Williamson et al. 1986) root growth. This variability may be due to the concentrations and methods of application used. Treatments that maximize the effects on shoot growth relative to root growth (i.e., foliar sprays) may result in increased root growth, whereas treatments that expose the roots to high concentrations of paclobutrazol may reduce both root and shoot growth.

It is uncertain whether the responses observed in roots of treated plants are a direct effect of paclobutrazol on root growth or an indirect effect resulting from shoot growth modification (such as a shift in resource allocation to the roots). Williamson et al. (1986) reported reductions in root growth of peach seedlings that received foliar treatments. If transport of the compound is primarily via the xylem (Lever et al. 1982), this would suggest an indirect effect on root growth by paclobutrazol.

In all species, application of paclobutrazol early in the cultural period generated a stronger response. Paclobutrazol is quite stable in the soil and is readily carried over in the field from one season to the next (Williams 1984), and accumulates in leaf tissues (Early and Martin 1988). Thus it seems reasonable to suggest that application late in the previous season (August) will allow greater uptake and will have a greater effect on growth the following season than application in April just prior to growth initiation.

Although paclobutrazol offers promise as a tool for manipulating conifer seedling growth in the nursery, the variable responses are discouraging. Moreover, the inhibitory effects on root growth in the nursery and persistent retardation of growth in the field are also unwanted. Controlling the degree and duration of paclobutrazol's effects is complicated by the influence of tree vigor (Tukey 1983), the method of application (Barrett and Bartuska 1982), its persistence in the soil (Williams 1982), and time of application (this paper). Future work should concentrate on (1) attaining the "optimum" response where shoot growth is retarded and root growth is stimulated, and (2) controlling the persistence of paclobutrazol in soil.

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Table 1.--Effect of paclobutrazol on morphology and field performance of jack pine, (JP), red pine, (RP), and Eastern larch (EL) seedlings. Morphology measurements are based on 15 seedlings, field responses are based on 30 seedlings.

			Morphology						Field performance		
Species	Appl time	Tmt. (mg/ plant)	Height (cm)	Caliper (mm)	Root area index	Shoot dry weight (g)	Root dry weight (g)	Shoot/ root (g/g)	Survival (%)	Height growth (cm)	Caliper growth (mm)
JP	Aug	0	29.4 a[1]	6.4 a	66.6	6.628 a	0.975 a	7.0	90.0	13.3 a	1.5
		0.5	25.8 ab	5.5 ab	73.5	5.362 ab	0.969 a	6.5	93.3	11.2 ab	1.5
		1.0	22.2 b	5.1 bc	64.3	4.730 bc	0.806 ab	7.2	96.7	11.2 ab	1.4
		5.0	15.3 c	4.3 cd	54.8	4.027 bc	0.600 ab	7.1	90.0	8.0 bc	1.3
		10.0	16.0 c	3.7 d	50.9	3.245 c	0.496 b	7.0	83.3	7.6 c	1.3
		20.0	13.6 c	3.7 d	50.9	3.045 c	0.527 b	6.7	100.0	7.0 c	1.3
JP	Apr	0	29.0	5.2	49.2	4.817	0.630	7.8	90.0	10.8 a	1.0
		0.5	30.3	5.9	71.4	6.646	0.869	7.9	73.3	10.8 a	1.1
		1.0	28.9	5.0	60.6	5.016	0.635	8.5	80.0	10.6 ab	0.7
		5.0	27.4	4.9	54.5	4.957	0.659	8.2	93.3	9.7 ab	0.9
		10.0	28.9	5.3	66.2	5.618	0.786	7.7	76.7	7.6 b	0.8
		20.0	27.0	5.6	71.6	6.435	0.933	7.4	100.0	7.9 b	0.9
RP	Aug	0	22.2 a	4.7 ab	47.1 ab	4.986 bc	0.640	8.8	43.3	5.4	0.8
		0.5	21.0 ab	4.3 abc	45.2 b	4.816 bc	0.515	9.8	56.7	5.2	0.8
		1.0	22.8 a	4.8 a	45.6 ab	5.967 a	0.574	11.0	60.0	4.0	0.8
		5.0	17.3 bc	3.8 c	49.1 ab	4.250 bc	0.450	10.9	33.3	3.2	0.6
		10.0	18.0 bc	3.9 bc	61.7 a	5.078 bc	0.704	7.7	40.0	3.9	0.7
		20.0	16.3 c	3.6 c	41.3 b	3.675 c	0.480	8.0	36.7	2.9	0.7
RP	Apr	0	24.8 a	5.0	47.4 b	6.778	0.781 ab	8.9 a	70.0	4.9 a	0.5
		0.5	22.5 ab	4.4	41.7 b	4.974	0.579 b	9.0 a	36.7	4.6 a	0.6
		1.0	21.9 ab	4.2	52.7 ab	5.730	0.568 b	10.4 a	26.7	3.4 ab	0.1
		5.0	19.8 b	5.1	71.5 a	5.892	1.041 a	5.8 b	56.7	4.2 a	0.3
		10.0	22.2 ab	4.6	50.6 b	6.299	0.688 ab	9.6 a	40.0	3.4 ab	0.1
		20.0	24.3 a	4.9	49.8 b	6.665	0.720 ab	9.7 a	43.3	1.5 b	0.1
EL	Aug	0	24.8 a	5.2 a	40.7	2.716 ab	1.253	2.4 ab	96.7 a	13.9 a	3.1 a
		0.5	26.4 a	5.7 a	43.8	3.367 a	1.409	2.5 ab	96.7 a	9.5 ab	2.6 ab
		1.0	26.3 a	5.2 a	39.3	2.635 ab	1.403	2.0 b	93.3 ab	12.5 a	3.1 a
		5.0	23.4 ab	5.3 a	43.0	3.362 a	1.154	3.1 a	96.7 a	10.5 ab	3.4 a
		10.0	13.2 bc	3.9 b	27.9	1.669 bc	1.207	2.1 b	90.0 ab	11.7 a	3.5 a
		20.0	8.6 c	3.2 b	28.5	1.108 c	0.661	1.8 b	56.7 b	6.1 b	1.5 b
EL	Apr	0	31.2 a	4.7	52.2	1.929	0.825	2.5	83.3	7.9	1.5
		0.5	26.4 ab	5.1	61.2	2.336	1.037	2.5	100.0	9.9	2.0
		1.0	28.7 ab	4.6	67.3	2.023	0.971	2.4	96.7	9.4	1.9
		5.0	28.8 ab	4.9	60.8	2.265	0.913	2.7	96.7	9.2	1.9
		10.0	25.6 b	5.0	57.5	2.387	1.030	2.5	96.7	9.6	2.0
		20.0	25.9 b	5.1	63.0	2.505	1.002	2.9	96.7	9.0	2.2

[1]Values within each group followed by the same letter are not significantly different at the 5% level. Groups without letters had no significant differences.

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Fixing the Edsel — Can Bareroot Stock Quality be Improved?[1]

David G. Simpson[2]

Abstract.--Bareroot stock quality and subsequent field survival and growth can be improved by: (1) - growing seedlings at wider spacings which results in increased dry weight, lower shoot/root ratio, larger root collar diameter and in some cases increased root growth capacity (RGC); (2) - root culturing (undercutting or root wrenching) which increases RGC; and (3) - nutrient loading with fall applications of nitrogen fertilizers which increases both RGC and field growth.

INTRODUCTION

A B.C. Ministry of Forests report (Errico and Pelchat 1984) which, by means of computer assisted linear programming, compared several nursery stock type options to produce interior spruce (Picea glauca and/or Picea engelmannii) planting stock suggested that if field performance was ignored, 85% of the spruce trees planted in BC should be produced as 2+0 bareroot stock. However, when field performance and increased morphologic standards were included in Errico and Pelchat's model, only 5% of spruce planting stock was to be produced as 2+0 bareroot stock. Poor field performance (survival) of the 2+0 bareroot stock was the reason the model projected such a radical shift in spruce stock types. Field performance, survival, and growth data are limited for most species planted in British Columbia. Collective opinion, however, seems in agreement that the 2+0 seedlings produced are not surviving in great enough numbers and those that survive often grow poorly.

There are two choices to resolve the preceding problem:

a) abandon bareroot 2+0 stock in favor of more successful stock types, or
b) adjust or modify the 2+0 bareroot stock cultural regime so that survival and growth is improved.

[1]Presented at the joint meeting of the Western Forest Nursery Council and the Forest Nursery Association of B.C., August 9-11, 1988, Vernon, B.C., Canada.

[2]The author is a Research Scientist with the British Columbia Ministry of Forests at Vernon, B.C.

To the recipient of nursery stock, the first option is the most obvious solution as he wants only a product that performs. However, if the field performance of the least cost stock type, the 2+0 bareroot seedling, can be improved by changing nursery cultural and field handling practices, the objective of obtaining the greatest number of surviving, "free-to-grow" seedlings at the least cost may be in reach.

This report has been prepared to present the results of several experiments conducted by the author since 1977 on various aspects of bareroot nursery culture. The common goal of all these experiments has been to improve the field performance of 2+0 bareroot planting stock by making relatively low cost changes to nursery cultural and handling practices. At the onset, 2+0 bareroot stock quality, or field performance potential, was considered to be so poor that any improvements made were certain to more than justify the research invested.

Within the bareroot seedlings' nursery environment, there are relatively few cultural factors which may be manipulated with great precision. Factors which may be controlled include: nursery location and soil, seedling espacement, root culturing, nutrients, irrigation, and lifting dates. The response, in terms of seedling field performance, to any specific cultural factor interacts somewhat with genotype and prior nursery culture. For this reason, a series of experiments were conducted with various species to investigate the separate effects of several nursery cultural factors on field performance. The combined effect of simultaneous changes to several cultural practices is best seen as the change in field performance of stock produce in past years relative to field performance of present day 2+0

planting stock planted on similar sites. Due to the scarcity of field performance data, quantitative comparison of past and present 2+0 stock is rarely possible. However, collective opinion would suggest that some field performance improvement has occurred, but certainly greater success must occur to attain the goal of least cost for surviving free to grow trees.

NURSERY LOCATION AND SOIL

Implementation of a root growth capacity (RGC) testing program in 1977 for testing of nursery stock at the B.C. Ministry of Forests' Red Rock (Prince George) and Skimikin (Salmon Arm) nurseries and casual observations of the relative field performance of stock from these two nurseries resulted in the perception that there were substantial and consistent stock quality differences between the two nurseries.

To determine to what extent "nursery" and "soil" affected stock quality and field performance, a reciprocal soil transfer experiment was undertaken. At each nursery, raised beds of each nursery's soil were established and along with a regular nursery bed, sown with lodgepole pine and interior spruce seed. Using similar fertilizer and root culturing regimes in all soil treatments, the seedlings were grown for 2 years. On Oct. 20 of the second growing season, the seedlings were handlifted and stored overwinter (ca. 6 mos.) at -2°C. In the spring (May), stored seedlings' RGC's were determined, and the seedlings were outplanted onto a forest site near Vernon, B.C.

First year field survival of the interior spruce was high (86 to 97%) and there were no significant ($p \leq 0.05$) nursery or soil effects. Lodgepole pine seedlings grown in raised nursery beds at Skimikin nursery had reduced survival, perhaps due to some unmeasured quality differences (fig. 1). Growth of surviving

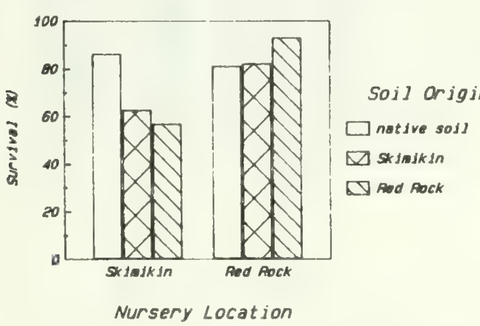

Figure 1.--First year field survival (%) of lodgepole pine grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

seedlings was not affected by nursery soil and only slightly by nursery location (for example, fig. 2).

There were no consistent effects of either nursery or nursery soil on RGC after storage (fig. 3); however, it was noted that lodgepole pine RGC's were consistently greater than those of interior spruce.

The conclusion drawn from this experiment was that the previously observed RGC differences between Skimikin and Red Rock nurseries must have been due to some cultural factor rather than nursery climate, or nursery soil.

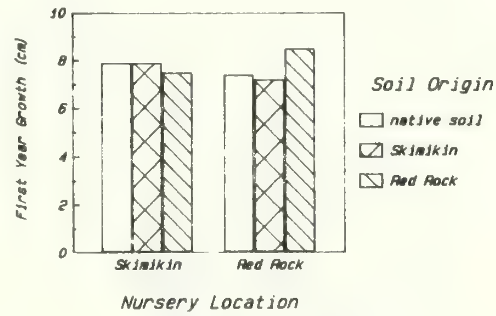

Figure 2.--Growth of surviving field planted lodgepole pine seedling grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

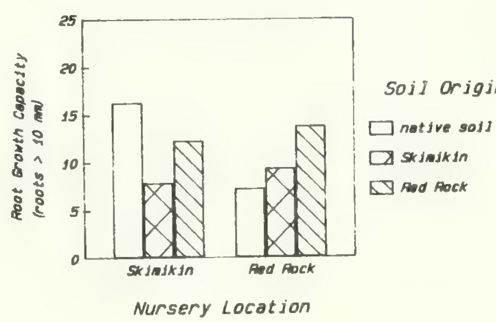

Figure 3.--Root growth capacity (RGC) of lodgepole pine grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

SEEDBED DENSITY

Whether a stand of trees be in a nurserybed or on a forest site, competition occurs between individuals. In the bareroot nurserybed, conventional sowing machines scatter seed in six to eight parallel drill rows that are approximately 15 cm apart. The distribution of

seed within the drill rows is often not uniform resulting in clumps of seedlings. To demonstrate that field performance of Douglas-fir and ponderosa pine 2+0 planting stock could be improved by growing the seedlings at reduced and more uniform seedbed densities, two experiments were initiated.

In May 1978 plots with four seedbed density levels: 74, 118, 172, and 259 Douglas-fir seedlings per m^2, were established by thinning seedbeds sown to create an operational density of 259 seedlings per m^2. After two growing seasons the 2+0 seedlings were lifted and planted on a forest site. Survival of all treatments was near 100%, however, there were significant growth differences in both the first and second year after outplanting (fig. 4).

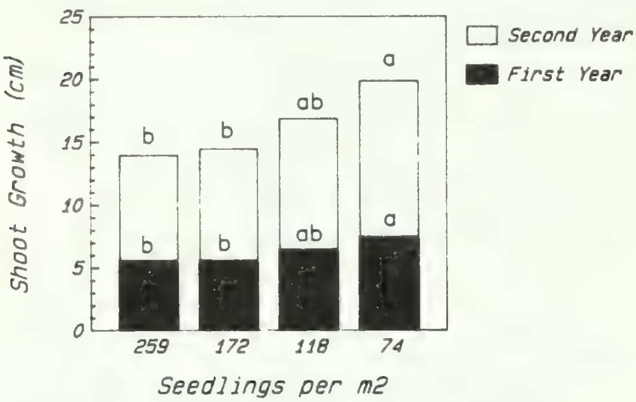

Figure 4.--Shoot growth (cm) of Douglas-fir seedling one and two years after planting on a forest site. For each year, means followed by a similar letter are not significantly different ($p \leq 0.05$).

The positive effect of reduced seedbed density on field performance was likely the result of larger seedlings being produced at the lower densities. While shoot height in the nursery was not affected by bed density reductions, both root collar diameter and seedling dry weight increased as density decreased (table 1).

Table 1.--Seedling spacing effects on Douglas-fir root collar diameter (mm), total dry weight (g) and shoot/root ratio. Means underlined by the same line are not significantly different ($p \leq 0.05$).

	Seedling Spacing (seedlings per m2)			
	259	172	118	74
Root Collar	3.5	4.5	4.9	5.8
Dry Weight	3.9	5.3	6.5	9.2
Shoot/Root	1.97	1.75	1.56	1.23

In 1979 a second experiment was established using ponderosa pine to investigate seedbed density levels of 80, 160, 240, and 290 seedlings per m^2. As in the earlier experiment with Douglas-fir, as ponderosa pine seedbed densities decreased; root collar diameters increased, seedling weights increased, and shoot:root ratios deceased (table 2).

Table 2.--Seedling spacing effects on ponderosa pine root collar diameter (mm), total dry weight (g) and shoot/root ratio. Means underlined by the same line are not significantly different ($p \leq 0.05$).

	Seedling Spacing (seedlings per m2)			
	290	240	160	80
Root Collar	4.2	5.1	5.2	6.3
Dry Weight	4.2	6.0	6.5	9.2
Shoot/Root	1.97	1.74	1.89	1.63

Significant positive improvements in both first year field survival and growth due to seedbed density reductions occurred when the ponderosa pine seedlings were planted on a forest site (fig. 5).

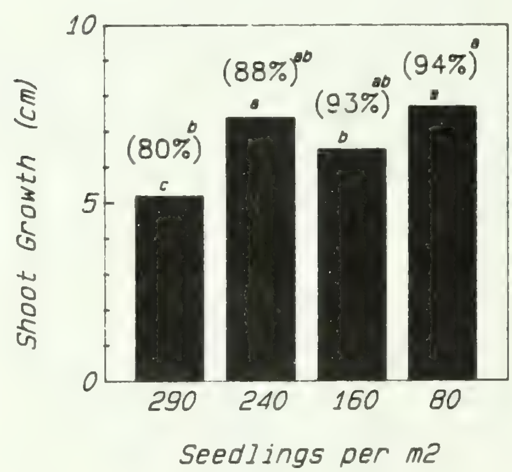

Figure 5.--Nursery bed spacing effects on first year survival (indicated in brackets) and shoot growth (bars) of outplanted seedlings. Means followed by similar letters are not significantly different ($p \leq 0.05$).

Often physical measures of nursery stock quality such as root collar diameters and shoot:root ratios are poor predictors of field performance because of variation in physiologic vigor or quality. Stored tissue nutrient levels and root growth capacity were measured to determine what seedbed density effects, if any, occurred. With Douglas-fir no significant differences in root growth capacity levels of seedlings raised at different seedbed density were observed, and of N, P, K, Ca, and Mg measured in root, stem and foliage tissue, only stem N levels were shown to increase as density decreased. This increase in stem N may reflect the proportionately greater amounts of bark and phloem tissue on the larger seedlings produced at low densities.

With ponderosa pine, tissue nutrient levels were not affected by seed bed density reductions. However, root growth capacity of seedling after over winter storage was higher in those seedlings grown at wider spacing (fig. 6).

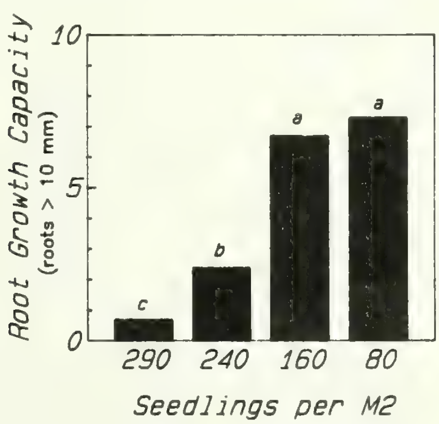

Figure 6.--Nurserybed spacing effects on root growth capacity (number of new roots longer than 10 mm per seedling) of ponderosa pine seedlings. Means followed by number letters are not significantly different ($p \leq 0.05$).

To summarize, in both experiments, seedlings produced at lower bed densities had better morphologic quality (greater dry weight; lower shoot:root ratio; larger root collar diameter) and in the case of ponderosa pine had improved root growth capacity levels. It is supposed that improvements to both morphologic and physiologic quality contributed to the superior field performance of the seedlings raised at lower densities.

ROOT CULTURING

Left undisturbed in the nursery bed, conifer seedlings produce a root system with long primary and secondary roots. This type of root system is well suited to exploitation of moisture and nutrients in the natural environment. However, if seedlings with a natural type root system are lifted, many of the second and higher order lateral roots necessary for new root regeneration on replanting are lost. A bareroot seedling for field planting must therefore be encouraged to develop a compact root system that will not be lost on lifting. Root culturing is used to produce compact fibrous root systems. There are three main root culturing practices: lateral root cutting, undercutting, and root wrenching.

Root pruning, as opposed to root cutting, refers to trimming of seedlings' root systems that may occur after the seedlings have been lifted from the nursery bed.

Lateral root cutting is accomplished by passing vertical blades or rolling coulters between the drill rows. This treatment is usually done during the second growing season, and promotes a bi-lateral shaped root system and tends to reduce the amount of root tearing which occurs during lifting and grading. Undercutting is done by passing a reciprocating horizontal blade through the seedbed to sever the primary and secondary roots at a depth of between 10 and 20 cm. In the late 1970's there were two main types of equipment used in B.C. forest nurseries: a "Marsh" undercutter having a fairly thick (5 mm) rigid blade that reciprocates fairly slowly, and a second, more recently introduced machine, the "Lotus" undercutter having a thin (2 mm) spring steel blade that reciprocates somewhat quicker. The Lotus machine makes a cleaner cut through the seedlings' root systems resulting in less bed disturbance such that a more shallow undercutting treatment is possible. The Marsh machine, by virtue of its more robust construction can travel through the seedbed at somewhat greater speeds.

Root wrenching is done using a non-reciprocating blade that is passed under the seedbed at an angle. This treatment results in a loosening of the bed, the degree dependent on the blades angle and speed through the seedbed. Root wrenching is usually done in the second growing season and often at a slightly greater depth than undercutting.

The effectiveness of root culturing, in particular, of undercutting and root wrenching, in promoting a more compact root system varies with species and nursery soil as well as severity, timing and frequency of treatment. To investigate the effectiveness of undercutting and wrenching in improving field performance potential, two experiments were conducted at the B.C. Ministry of Forests' Surrey, Skimikin, and Red Rock nurseries. The first experiment manually simulated shallow undercutting and root wrenching at weekly intervals from late July until mid-October of the 2+0 stock's second growing season.

There were no consistent effects on seedling height, root collar diameter or shoot and root dry weights which would be attributed to the undercutting and wrenching treatments. However, root systems of seedlings receiving undercutting or wrenching treatments were noted to be more compact and fibrous than were the root systems of seedlings receiving no root culturing.

Seedlings produced in this experiment were not field planted, however, root growth capacity measurements made in the spring after 24-weeks of -2°C cold storage suggests that the undercutting and wrenching treatments in some cases significantly increased this indicator of field performance potential (fig. 7).

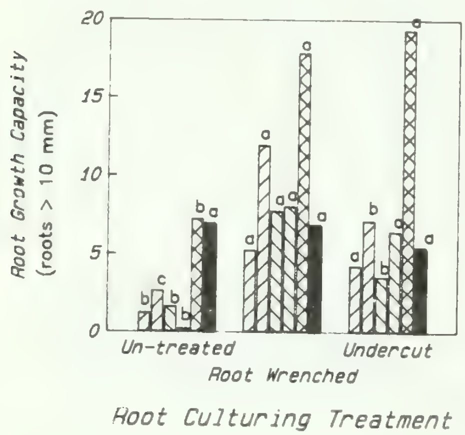

Figure 7.--Root culturing effects on root growth capacity (number of new roots longer than 10 mm per plant) of white spruce (right hatch), Engelmann spruce (left hatch), lodgepole pine (cross hatch) and Douglas-fir (solid). Within each species, means followed by similar letters are not significantly different ($p \leq 0.05$).

Except in Douglas-fir, the effects of the root wrenching treatment on post-storage root growth capacity was equal to or better than the undercutting treatment.

The manual root wrenching treatment used in this experiment was more severe, and at a shallower depth than the machine root wrenching usually practiced in British Columbia nurseries. A second experiment to determine if similar results could be obtained using a standard wrenching bar for the root wrenching and the thin blade "Lotus" undercutter was conducted at the B.C. Ministry of Forests' Skimikin Nursery beginning in 1981.

The results from this experiment (fig. 8) suggests that root wrenching (RW) resulted in slightly shorter seedlings, but that the field growth of these seedlings was similar to seedlings receiving the undercut (U) treatment.

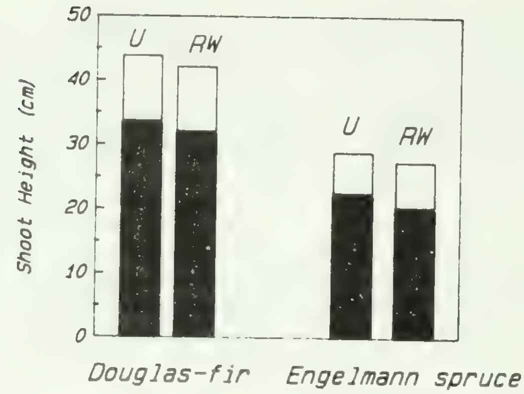

Figure 8.--Root culturing effects on average height of seedlings in the nursery (solid bar) and after one year on a forest planting site (open bar). U= undercut only; RW= root wrenched.

The conclusion drawn from these root culturing experiments is that as field performance of root wrenched and undercut seedlings seems to be similar, and likely better than non-root cultured seedlings, that the choice of root culturing method should be based on operational preference.

NUTRIENT LOADING OR FALL FERTILIZATION

Moisture stress and reduced fertilization are often used in forest nurseries to slow shoot growth, induce dormancy, and promote cold hardening of conifer nursery stock (Burdett and Simpson 1984). These practices can contribute to reduced tissue nutrient levels. Several authors (Anderson and Gessel 1966; Benzian et al. 1974; van den Driessche 1984) have reported improved field performance attributable to fall fertilization. Earlier experiments in B.C. nurseries (Donald and Simpson 1985) found that fall fertilization of seedlings with a balanced fertilizer (4-12-8) improved both root growth capacity and first year growth after outplanting.

To separate the effects of nitrogen (N), phosphorus (P), and potassium (K) on RGC and performance of outplanted stock, an experiment was undertaken at two interior nurseries (Red Rock near Prince George, B.C. and Skimikin near Salmon Arm, B.C.) and one coastal nursery (Surrey near Vancouver, B.C.). Four species were treated: white spruce ; Engelmann spruce ; lodgepole pine ; and interior Douglas-fir . Fifteen fertilizer treatments were applied to 2+0 bareroot seedlings 6 to 8 weeks before their being lifted to overwinter cold (-2°C) storage.

Root growth capacity was measured after a storage period of approximately 6 months (October-November to early May) and outplantings

were established in irrigated but not fertilized transplant beds at Skimikin nursery. Significant RGC improvements in spruce from both Red Rock and Skimikin nurseries occurred only in those fertilizer treatments containing N (fig. 9). The RGC response was greater in Skimikin-grown stock than in Red Rock-grown stock and may be related to the higher N-uptake. Spruce stock which received N at a rate of 500 kg/ha 34-0-0 had foliage N levels increased from a level of 1.9% to 3.1% at Skimikin nursery and 1.5% to 2.0% at Red Rock nursery. Spruce stock treated at Surrey Nursery failed to show a RGC improvement, perhaps because little uptake of N was observed.

Lodgepole pine from Red Rock nursery regenerated large numbers of roots in all treatments, and there were significant RGC improvements in those fertilizer treatments containing N. Douglas-fir at Skimikin Nursery responded similarly, having higher RGP levels in those treatments containing N (fig. 9).

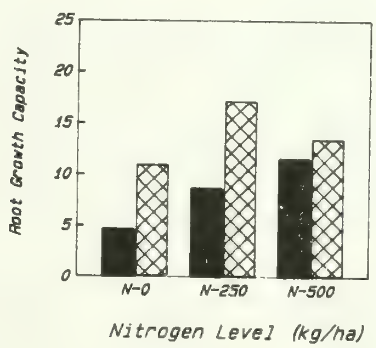

Figure 9.--Nutrient loading effects on root growth capacity (number of new roots longer than 10 mm per plant) of interior spruce (solid bar) and Douglas-fir (cross hatch bar). Means indicated are pooled values for treatments at Skimikin nursery where nitrogen (as 34-0-0) was applied at 0, 250, or 500 kg/ha.

Phosphorus applied singly, or in combination with other nutrients as top dressings was not taken up by any of the species, and there were no treatment effects on RGP or growth after outplanting. Potassium content was only slightly increased by fall applications of K; however, it was noted that N application decreased foliar K levels.

First year growth responses after outplanting were similar (fig. 10) to the RGC responses to fall fertilization treatment wherein those treatments containing N resulted in improved shoot growth.

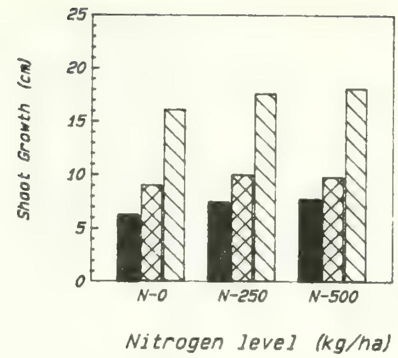

Figure 10.--Nutrient loading effects on root growth capacity (number of new roots longer than 10 mm per plant) of interior spruce (solid bar), Douglas-fir (cross hatch), and lodgepole pine (right hatch). Means indicated are pooled values for treatments at Skimikin and Red Rock nurseries where nitrogen (34-0-0) was applied at 0, 250, or 500 kg/ha.

In summary, significant positive improvements in post-storage RGC and subsequent field performance of 2+0 bareroot spruce, Douglas-fir and lodgepole pine nursery stock at interior nurseries should be expected with addition of N as 34-0-0 at rates of 250-500 kg/ha 6 to 8 weeks prior to lifting to overwinter (ca. 6- to 8-month) storage at -2°C. Spruce at coastal nurseries, such as Surrey, are not expected to respond to late season fertilizations as undertaken in this experiment.

OPERATIONAL TRIAL

Once it had been established that substantial improvements to bareroot nursery stock quality could be obtained by bed density reduction, root culturing, and nutrient loading, an operational demonstration of the combined effectiveness of these practices was undertaken.

The demonstration consisted of six 120 m long seedbeds sown with interior Douglas-fir, lodgepole pine, and white spruce. These beds were divided in half with the first 60 m of each bed receiving "normal" nursery culture (circa 1980-81) and the second 60 m receiving "improved" culture.

Seedbed density was reduced about one-half (table 3). Root culturing in the "improved culture" consisted of fortnightly wrenching at 15 cm depth from July 15-Sept. 30, while root culturing in the normal culture area was done much less frequently (exact details not available). Fall fertilization was applied as a single application of 34-0-0 fertilizer at

250 kg/ha on Sept. 1, which was 6 weeks prior to lifting. With the exception of the single fall fertilization, both normal and improved seedbeds received identical fertilizer applications.

First year field performance of the spruce was not measured; however, one Douglas-fir seedlot was outplanted as were two lodgepole pine seedlots. The results from these plantings (fig. 11) suggest that the seedlings grown with the improved cultural practice had significantly better first year field performance.

Table 3.--Operational demonstration.

Factor	Normal Culture	Improved Culture
Bed Density	180–360	115–130
Root Culture	occasionally	fortnightly
Nutrient Loading	none	250 (34-0-0)

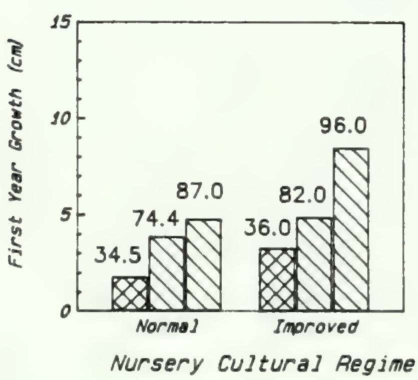

Figure 11.--First year survival (%) and growth (cm) of Douglas-fir (cross hatch) and lodgepole pine (right hatch) which received "normal" and "improved" nursery cultural regimes.

CONCLUSION

The data obtained in the preceding experiments suggests that there is potential to improve the field performance of 2+0 bareroot seedling for use in reforestation through relatively low cost changes to the nursery cultural practices used to grow this stock type. The economic efficiency of this stock type suggests it should receive serious consideration as a reforestation alternative.

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ACKNOWLEDGEMENTS

The author wishes to thank the staff and management of the Surrey, Skimikin and Red Rock forest nurseries for their assistance in conducting many of these experiments.

Effect of Controlled-Release Fertilizers on Formation of Mycorrhizae and Growth of Container-Grown Engelmann Spruce[1]

Gary A. Hunt[2]

SUMMARY

Two controlled-release NPK formulations (Osmocote and Nutricote) and one micronutrient formulation (Micromax) were added as supplements to a soluble fertilizer regime and evaluated for their effects on seedling growth and development of naturally occurring mycorrhizae in 1-0 container-grown seedlings of *Picea engelmannii* Parry. Treatments were (all received identical amounts of soluble fertilizer): 1) Osmocote, 2) Nutricote, 3) Osmocote + Micromax, 4) Nutricote + Micromax, 5) Micromax, 6) soluble only. Seedlings supplemented with Osmocote or Nutricote had lower root weight, but greater shoot length, stem caliper and total weight compared to controls receiving only soluble fertilizer. Addition of Micromax did not alter growth compared to controls, but Micromax plus Osmocote decreased shoot length and shoot:root ratio compared to Osmocote alone; Micromax plus Nutricote increased shoot length compared to Nutricote alone. Seedlings receiving a supplement of Micromax alone or given only soluble fertilizer did not meet minimum standards for caliper or shoot length set by the B. C. Forest Service.

Five types of mycorrhizal fungi established naturally during the study. Feeder roots of treatments receiving Osmocote or Nutricote were predominantly colonized by *Thelephora terrestris* at percentages ranging from 72 to 97. This contrasted with nonsupplemented treatments where *Thelephora* was substantially reduced (mean of 38 percent colonization) and E-strain formed a major component of total colonization. Percentage of nonmycorrhizal feeder roots was highest when Osmocote was used (16 percent), but did not exceed six percent in other treatments. Osmocote was also detrimental to mycorrhizal diversity compared to nonsupplemented controls; one fungus was present with Osmocote (*Thelephora terrestris*) compared to four fungal types in nonsupplemented controls.

In two supplemental experiments, effects of different release rates (types) of Nutricote and two rates of one type were examined. Comparison of four types of Nutricote (70, 100, 140, and 180-day release rates) showed few effects of release rate on growth. Compared to the 100-day formulation, the 70-day formulation produced greater stem caliper. Seedlings receiving 70 or 140-day supplements had greater shoot:root ratio, and shoot length was approximately 3 cm greater than trees with 100 or 180-day supplements. Mycorrhizal colonization did not differ substantially among the types, although E-strain colonized at low levels (up to 11 percent) with Types 100 or 140 and was absent in the others.

In a comparison of two rates of Nutricote Type 70 (1.9 and 4.7 Kg m^{-3}), little effect on shoot growth was evident (dry weight of roots was higher and shoot:root ratio reduced at the lower rate), but fungal diversity and colonization by E-strain were decreased at the the higher rate.

Data comparing growth of seedlings predominantly colonized by E-strain or *Thelephora* demonstrated that E-strain significantly increased stem caliper, dry weight of roots, total seedling weight, and improved the Dixon Quality Index value.

When supplementing soluble fertilizers with controlled-release NPK formulations for optimizing seedling balance and root development, the rate of the supplement should be the minimum required for obtaining acceptable seedling size and tissue nutrient content.

A detailed report of this study is being prepared for journal publication.

[1]Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2]Gary A. Hunt is Research Scientist, Balco Canfor Reforestation Centre Ltd., Kamloops, B. C.

Growth of Chemically Root-Pruned Seedlings in the Greenhouse and the Field[1]

David L. Wenny[2]

Abstract. -- Cupric carbonate treated containers produced ponderosa pine, western white pine and Douglas-fir seedlings with a more natural lateral root distribution than controls. Treatment has not increased survival or height growth after three field seasons.

INTRODUCTION

Root morphology differs between natural and container-grown seedlings. Natural seedlings generally develop a well distributed lateral root system providing mechanical stability and maximum growth potential (Stein 1978). Container-grown seedlings frequently have long lateral roots directed downward along the container wall until air-pruned at the drainage hole. In the field, such seedlings often have limited lateral root egress from upper portions of the plug but a high concentration of root egress from the plug base. Restricted root egress may reduce potential survival, growth, and mechanical stability, particularly on drier sites. Burdett (1978a,b) reported root elongation of container-grown lodgepole pine (Pinus contorta Dougl.) seedlings was completely inhibited upon contact with container walls coated with cupric carbonate. After outplanting, lateral roots of treated seedlings egressed from the upper portion of the root plug in a pattern similar to a natural root system (Burdett 1981; Burdett and others 1983). McDonald and others (1981) found similar results with ponderosa pine (Pinus ponderosa Laws. var. ponderosa Engelm.). Wenny and Woollen (1988) used this cupric carbonate technique for root pruning northern Idaho sources of western white pine (Pinus monticola Dougl.), ponderosa pine, and Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco) seedlings. We found a significant increase in root egress from the upper portions of the plug in growth room tests. First year field results of these seedlings did not increase significantly in growth or survival rates (Wenny and others 1988).

METHODS

Northern Idaho sources of Douglas-fir, ponderosa pine, and western white pine seedlings were chemically root-pruned while growing in the University of Idaho Research Nursery greenhouse. Two Ray Leach® pine cell trays (200 cells per tray) and two Styroblock 4A trays (198 cavities per tray) were used for each species. Forty pine cells per tray and 39 cells per styroblock (each 66 cm^3) were randomly assigned one of five treatments: an unpainted control; or a latex paint coating containing cupric carbonate at concentrations of 0, 30, 100 or 300 gL^{-1}. Since previous research with chemical root pruning by Burdett (1978) and McDonald (1981) found a concentration of 100 gL^{-1} $CuCO_3$ was effective in inhibiting root growth, the 30, 100, and 300 gL^{-1} concentrations were chosen in an attempt to bracket an optimal concentration for the species studied. Containers were filled with 1:1 peat:vermiculite forestry potting mix. Seeds were sown and the containers placed on greenhouse benches to receive species specific Research Nursery growing regimes (Wenny and Dumroese 1987a,b). Seedling height and root collar diameter measurements were taken at monthly intervals during the growing season. Data collected were subjected to conventional analyses of variance and Fisher's protected LSD.

Growth Room Tests

Dormant seedlings were removed from the containers (February), and placed into cold storage at 2°C. A root growth potential test (Duryea 1984) was initiated to evaluate effects of chemical root pruning on root system morphology. Ten seedlings from each container type and treatment combination were planted into 1-gallon pots containing 1:1 peat:vermiculite forestry potting mix. The potted seedlings were placed in a growth room following a split plot randomized complete block design. Growth room

[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association. Vernon, British Columbia. August 8-11, 1988.

[2]Idaho Forest, Wildlife and Range Experiment Station Contribution No. 403.

[3]David L. Wenny is Associate Professor of Regeneration and Manager Forest Research Nursery, University of Idaho, Moscow, Idaho.

temperatures were 27°C during the 16 hour day and 21°C at night. To obtain a 16 hour photoperiod, light energy reaching the canopy at an intensity of 220 $uEm^{-2}s^{-1}$ was provided by fourteen 96 inch Grow-Lux fluorescent bulbs. Root measurements were collected from three zones: top, middle, and bottom. New roots, longer than 1 cm, emerging from the plug were measured, counted and weighed for each separate zone. Root dry weights were obtained after oven drying at 60°C for 24 h. Seedling height, root collar diameter, shoot dry weight, the number, length, and dry weight of new roots by root zone, and total root length values were subjected to conventional analyses of variance and Fisher's protected LSD.

Field Tests

In April, seedlings were planted on the University of Idaho Experimental Forest. A randomized complete block design with three replicates was used. Ten seedlings of each species for each tray type and treatment combination were randomly assigned within a block. After the first growing season, survival, height, root collar diameter, shoot and root dry weights, and new root number were measured. Survival and growth data were collected after the second and third growing seasons. The plantation will be re-examined in the future.

RESULTS & DISCUSSION

Greenhouse and Growth Room

Shoot growth was uninfluenced by treatment during greenhouse culture. Height and root collar diameter measurements were not significantly different at any time during the growing season (April - October). Observation of root development showed nontreated seedlings had many more long, lateral roots running longitudinally along the plug wall, while treated seedlings had most lateral roots pruned at the plug wall.

Growth room data indicate seedling height, root collar diameter, and shoot dry weight was unaffected by treatment, regardless of species and container combinations. Root development did show a treatment affect with greater new root numbers, dry weights, and lengths in the top and middle plug zones of cupric carbonate treatments. These results were significant for most species and container combinations and are best illustrated by combining total new root length for the upper zones (Table 1). Increases in total length and total number of roots from chemical root pruning probably occurred because 1) primary, secondary, and tertiary chemically pruned lateral roots resumed growth from the upper portions of the root system after planting and 2) pruning enhanced initiation of higher order laterals. In contrast, unpruned seedlings, with primary and secondary lateral root tips at the plug bottom, lack this growth resumption in the upper portions of the root system. Although unpruned seedlings still initiate higher order laterals in the upper root plug, it is not at the enhanced rate of chemically pruned roots.

Field Performance

After one field season, all $CuCO_3$ treatments display a trend of greater new root numbers in

Table 1. Mean total root length (cm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	730 BC	1304 AB	431 B	276 C	567 B	783 C
Paint	550 C	646 B	908 B	144 C	736 B	1137 C
30 gL^{-1}	739 BC	1610 AB	2292 A	1134 AB	1061 B	3088 A
100 gL^{-1}	1528 AB	2046 A	2347 A	1433 A	1306 B	2531 AB
300 gL^{-1}	2292 A	1628 AB	897 B	874 B	3782 A	1382 BC
LSD	800	1091	1352	520	1165	1250

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

the upper two-thirds of the plug for all species, but the difference is not significant for all container types (Table 2). A trend of reduced new root numbers in the lowest root zone occurs with $CuCO_3$ treatment, but is not significant with all tray types (Table 3). No trend appears when new root numbers throughout the plug are totaled (Table 4). This suggest cupric carbonate treatments did not increase the total number of new roots, but altered root distribution within the plug, increasing the proportion of roots in the upper two-thirds of the plug.

Examination of new root dry weights in the upper plug shows a general increase with a $CuCO_3$ treatment (Table 5). New root dry weights tend to decrease with treatment in the lowest root zone (Table 6). In neither case are differences significant with all species and tray type combinations. When root dry weight data is combined for all root zones (Table 7), no trend is apparent. Some seedlings had few new roots but their dry weights were high because of secondary, tertiary, and higher order lateral roots. Conversely, some seedlings had many new primary roots yielding low dry weights.

Seedling survival, height growth and root collar diameter after outplanting was unaffected by treatment during the first three years. Root redistribution, with greater numbers and lengths of new roots in the upper portions of the plug, did not result in seedling growth differences. Burdett (1981) also found seedling growth was not increased until after the third growing season when a 15% height increase was detected. Root egress on sampled seedlings did not differ between controls and treated seedlings for Douglas-fir. For pines, root egress was greater from the upper portions of the plug since the controls had more long laterals directed downward along the plug walls.

Management Implications

A planted seedling's root morphogenesis is dependent upon the elongation of existing roots and the initiation of new roots along the plug wall. Root elongation and initiation are influenced by 1) nursery cultural practices, 2) planting medium, and 3) planting tool. Our field results, to date, have not shown benefit from chemical root-pruning treatments. This may be due to the high degree of nontreated seedling root egress. In circumstances where cultural or handling/storage practices produce seedlings with excessive long lateral roots or media is compacted in the planting operation, chemical root-pruning may prove to have more immediate benefit.

ACKNOWLEDGEMENTS

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Table 2. Mean number of new roots (> 1 cm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	20 A	16 BC	13 B	14 A	18 C	19 B
Paint	18 A	14 C	13 B	17 A	27 B	22 B
30 gL^{-1}	23 A	31 A	23 A	20 A	34 AB	35 A
100 gL^{-1}	21 A	27 AB	28 A	17 A	38 A	28 AB
300 gL^{-1}	26 A	27 AB	27 A	17 A	28 B	25 AB
LSD	NS	11	8	NS	8	12

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 3. Mean number of new roots (> 1 cm) in the bottom root zone for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	30 A	16 A	16 A	15 A	24 A	17 A
Paint	16 B	12 AB	10 A	16 A	23 A	13 AB
30 gL^{-1}	12 B	15 AB	11 A	14 AB	13 AB	12 AB
100 gL^{-1}	7 B	7 B	11 A	7 B	24 A	10 AB
300 gL^{-1}	9 B	9 AB	10 A	12 AB	11 B	5 B
LSD	10	9	NS	7	11	8

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 4. Mean number of new roots (> 1 cm) in all root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	49 A	32 AB	29 AB	29 A	42 B	35 A
Paint	34 B	26 B	23 B	33 A	50 AB	35 A
30 gL^{-1}	35 AB	46 A	35 A	34 A	46 B	47 A
100 gL^{-1}	27 B	33 AB	39 A	24 A	61 A	38 A
300 gL^{-1}	35 AB	35 AB	36 A	29 A	40 B	31 A
LSD	15	17	11	NS	14	NS

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 5. Mean new root dry weight (gm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.43 B	0.40 B	0.31 B	0.37 A	0.77 A	0.92 B
Paint	0.38 B	0.47 AB	0.50 AB	0.41 A	0.97 A	1.00 B
30 gL^{-1}	0.73 A	0.85 A	0.80 A	0.56 A	1.29 A	1.47 A
100 gL^{-1}	0.52 AB	0.58 AB	0.69 AB	0.49 A	1.05 A	1.14 AB
300 gL^{-1}	0.61 AB	0.65 AB	0.72 AB	0.76 A	1.06 A	1.07 AB
LSD	0.27	0.38	0.43	NS	NS	0.46

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 6. Mean new root dry weight (gm) in the bottom root zone for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.30 A	0.33 A	0.33 A	0.52 A	0.53 A	0.48 A
Paint	0.20 AB	0.26 AB	0.39 A	0.32 A	0.57 A	0.59 A
30 gL^{-1}	0.15 AB	0.28 AB	0.41 A	0.41 A	0.45 A	0.55 A
100 gL^{-1}	0.07 B	0.11 B	0.31 A	0.23 A	0.57 A	0.58 A
300 gL^{-1}	0.10 B	0.17 AB	0.12 A	0.50 A	0.41 A	0.30 A
LSD	0.16	0.20	NS	NS	NS	NS

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 7. Mean new root dry weight (gm) in all root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.73 A	0.73 AB	0.64 B	0.89 A	1.30 A	1.40 A
Paint	0.58 A	0.73 AB	0.87 AB	0.73 A	1.55 A	1.59 AB
30 gL^{-1}	0.88 A	1.13 A	1.21 A	0.97 A	1.74 A	2.01 A
100 gL^{-1}	0.61 A	0.69 B	1.00 AB	0.73 A	1.62 A	1.72 AB
300 gL^{-1}	0.71 A	0.83 AB	0.84 AB	1.23 A	1.47 A	1.37 B
LSD	NS	0.41	0.56	NS	NS	0.61

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

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Effect of Nursery Culture on Morphological and Physiological Development of Western Hemlock Seedlings[1]

J.T. Arnott, B.G. Dunsworth, and C. O'Reilly[2]

Abstract.—Western hemlock seedlings were grown in two container sizes, subjected to short days and moderate moisture stress in July, lifted at three dates during the winter and cold stored for periods of up to four months. The influence of these cultural treatments on seedling morphology and physiology was measured. Short days effectively stopped shoot growth extension; moisture stress did not. Root growth capacity and dormancy release tests indicated a preference for lifting hemlock immediately before planting in mid-March, or after two months of cold storage from a mid-January lifting date.

INTRODUCTION

Variation in seedling survival and growth after outplanting reflects differences in the quality of the seedlings as they leave the nursery (Ritchie 1984). Quality is defined by certain morphological and physiological criteria and, because it is essential to successful plantation establishment, it has been the subject of considerable research and review (Bunting 1980; Duryea 1985; Ritchie 1984; Schmidt-Vogt 1981; Sutton 1979). Advances in nursery technology and containerized stock rearing (Scarratt et al. 1981; Tinus and McDonald 1979) provide many nurseries with the ability to grow a wide range of seedling types with different morphological and physiological characteristics. However, these seedling characteristics must be tailored for specific ecological conditions at the planting site and nursery growers must have the knowledge and experience to grow specific seedling stock types for a particular site.

A comprehensive study was made of the effects of nursery cultural regimes on the growth, development, morphology and physiology of container-grown western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings. This paper reports the influence of container cavity size, dormancy induction regime, time of lift, and duration of cold storage on the morphology and physiology of the seedlings. Results of other aspects of the nursery experiment will be reported elsewhere (O'Reilly et al. 1989a, 1989b) while the early growth response of these different types of seedlings after outplanting will be reported by O'Reilly et al. (1989c) at this meeting.

MATERIALS AND METHODS

Western hemlock seeds (British Columbia Forest Service, Registered Seedlot No. 3097; Lat. 48°39'N, Long. 123°39'W; Elevation 760 m) from Vancouver Island were stratified at 2°C for four weeks before sowing February 12, 1986 in BC/CFS styroblocks (Beaver Plastics Ltd., Edmonton, Alberta)[3] of small (PSB 313[4] abbreviated to S3) and large (PSB 415B[4] abbreviated to S4) cavity diameters. The styroblocks were placed in an experimental greenhouse at the Pacific Forestry Center, Victoria, B.C. (Lat. 48°28'N) maintained at 21°/18°C (day/night), 50 % humidity and an 18-h photoperiod. Natural day length was supplemented by high pressure sodium vapour lights

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[3]Mention of specific commercial products and formulations does not constitute endorsement by the Canadian Forestry Service.

[4]PSB 313 and PSB 415B styroblocks have respective cavity diameters of 27 and 35 mm, ribbed cavity volumes of 57 and 102 cm^3 and spatial densities of 932 and 526 cavities·m^{-2}

that provided a photon flux density of at least $6\ \mu mol \cdot s^{-1} \cdot m^{-2}$ (500 lx) at the seedling level. The styroblocks contained a 3:1 mixture of peat and vermiculite with $2.0\ kg \cdot m^{-3}$ dolomite lime (10 mesh and finer) added. The styroblocks were misted daily during germination, and fertilized with biweekly applications of 20N-20P-20K fertilizer with micronutrients (Green Valley Fertilizer, Surrey, B.C.) at $500\ mg \cdot L^{-1}$ and every two weeks with the heptahydrate form of ferrous sulphate at $155\ mg \cdot L^{-1}$. After September 15, greenhouse temperatures were set a 18°/15°C (day/night) until September 29, 15°/10°C until October 27, 15°/5°C until November 17, and 10°/5°C, thereafter.

Dormancy Induction Treatments

The seedlings were subjected to four dormancy induction regimes; a long- or short-day photoperiod of 18 h and 8 h, respectively, under conditions of moderate moisture stress (dry) or no moisture stress conditions (wet). In this section we use the term dormancy to mean a suspension of shoot length growth without specifying the physiological state of the plant (Downs and Bevington 1981) or the stage of bud development (O'Reilly et al. 1989b). The objective of applying these dormancy induction regimes, and growing the seedlings in small and large containers, was to create a range of different morphological seedling types. Induction regimes began on July 15, 1986, five months after seeding, and ended four weeks later. Styroblocks in the moisture stress treatments were allowed to dry down to 2.8 (S3) and 3.1 (S4) kg below their saturated weight before re-watering to saturation with 20N-20P-20K fertilizer added. This dry-down was repeated three times during the four-week dormancy induction period. Predawn xylem water potentials of the seedlings before rewatering to saturation averaged -1.0 MPa. Seedlings in the no stress treatments received water and nutrients as described under materials and methods above. Following the dormancy induction treatments, the water-soluble fertilizer was changed to 10N-52P-17K (Green Valley Fertilizer) at $500\ mg \cdot L^{-1}$ and the seedlings were grown under the above-described temperature regime and naturally-declining photoperiods.

Lifting Date/Cold Storage Treatments

The final phase of the nursery experiment studied the influence of lifting date and cold storage duration on seedling development. The objective was to create a range of physiological seedling qualities within each stock type by altering the lifting date and duration of cold storage. Seedlings were extracted from the styroblocks in mid-November 1986, mid-January and mid-March, 1987 and placed in 1°C rooms for 4, 2 and 0 months cold storage, respectively.

Nursery Experimental Design

A split-plot design was used in the layout of the experiment. Daylength was randomized between halves of the greenhouse and moisture regime between quarters within each half. Each quarter of the greenhouse was divided into eight blocks. Within each of the eight blocks, a group of styroblocks representing each container cavity size (S3 and S4) were randomly assigned to one of the three lifting dates. Analysis of variance of the morphological data were used to test for treatment effects and their interactions (Steele and Torrie 1980). The analyses are not presented in this paper although they are used in data interpretation. We present data means and their standard errors in the figures.

Measurements of Seedling Morphology

Shoot elongation of five seedlings within each of the eight blocks per treatment combination of container size, day length and moisture regime were measured at 1-2 week intervals from June 6 until October 17, 1986 (40 seedlings per treatment combination).

In another subsample, three seedlings from each of the eight blocks per treatment combination were randomly selected and extracted at each of the three lift dates for determination of shoot and root dry weights, and root collar diameter (24 seedlings per treatment combination per lift date = 192 seedlings per lift date).

Measurements of Seedling Physiology

At each lifting date, seedling subsamples were randomly extracted for testing in each of the lift/cold storage treatments (table 1). Root growth capacity (RGC) (Burdett 1979) and dormancy release index (DRI) (Ritchie 1984) were measured on equal numbers of seedlings at each of the three treatment periods A-C. For each test, eight replicates of three seedlings each per treatment combination (container size; photoperiod; moisture regime) were grown in pots containing a 3:1 mixture of peat and vermiculite with $2\ kg \cdot m^{-3}$ dolomite lime added. The pots were placed in a completely random design within growth rooms with day/night temperatures set at 22°/18°C, 55 % relative humidity, and a photoperiod of 16 h provided by mixed fluorescent and incandescent lighting with a photosynthetic photon flux density of $200\ \mu mol \cdot s^{-1} \cdot m^{-2}$. Growth room temperatures for the test were as prescribed by D. Simpson (Kalamalka Research

Table 1.—Summary of test periods for the lift date/cold storage treatment combinations.

Lift Date	Cold Storage Duration (Months)		
	0	2	4
Nov. 15	A	B	C
Jan. 15	B	C	
Mar. 15	C		

Period A: 8 treatments
Period B: 16 treatments
Period C: 24 treatments

Station, B.C. Forest Service, personal communication, Oct. 2, 1985).

Seedlings being tested for RGC were extracted from the pots 1 week later, the soil media carefully removed from around the root plugs and the new white growing tips (> 1 cm in length) scored using Burdett's (1979) semiquantitative scale of 0 to 5.

Seedlings being tested for DRI were placed in the growth rooms under similar conditions to the above. The pots were watered twice a week to maintain soil moisture level at, or near field capacity. Seedlings were assessed daily to determine the number of days to terminal budbreak (DBB); buds were considered to have broken when the bud scales parted and needles extended at least 1 to 2 mm. The dormancy release index values were calculated after the equation [1] given by Ritchie (1984). Fully chilled western hemlock seedlings take 9 days to break bud; hence the numerator = 9. Therefore, at the peak of winter dormancy, as defined by Doorenbos (1953), seedlings have a DRI value near 0; when nearing full release from winter dormancy, the DRI value approaches 1. Data from the RGC and DRI tests were subjected to analysis of variance according to a completely random design.

$$[1]\ \mathrm{DRI} = \frac{9}{\mathrm{DBB}}$$

RESULTS

Seedling Morphology

Container size had a significant (P<0.001) influence on seedling height growth with seedlings in the S3 container being shorter than those in the larger S4 container. As this trend was consistent across all morphological variables measured, only data from the S4 container (PSB 415B) are presented (fig. 1). There were no interactions among the main treatment effects of container size, daylength and moisture regime for seedlings sampled at the end of the growing season.

Seedlings exposed to short days ceased shoot elongation by the end of the dormancy induction treatment period (week 26). Shoots of seedlings under long days continued to extend until mid-October when they formed a terminal bud (week 35) (fig. 1). Moisture stress significantly (P<0.001) reduced shoot length but not to the same degree as was achieved with short days. Moisture availability primarily influenced the rate of growth whereas short days affected the phenology of growth.

By mid-January (Lift 2), short days, moisture stress, or both of them produced seedlings with significantly smaller shoot dry weights that those grown under no moisture stress and long days (fig. 2a). In relative terms, moisture stress usually resulted in a greater reduction of shoot dry weight and stem diameter than exposure to short day lengths (fig. 2a and 2c). Exposure to short days did not result in a significant reallocation of dry matter to the roots and moisture stress under long or short days simply reduced root dry weight (fig. 2b)

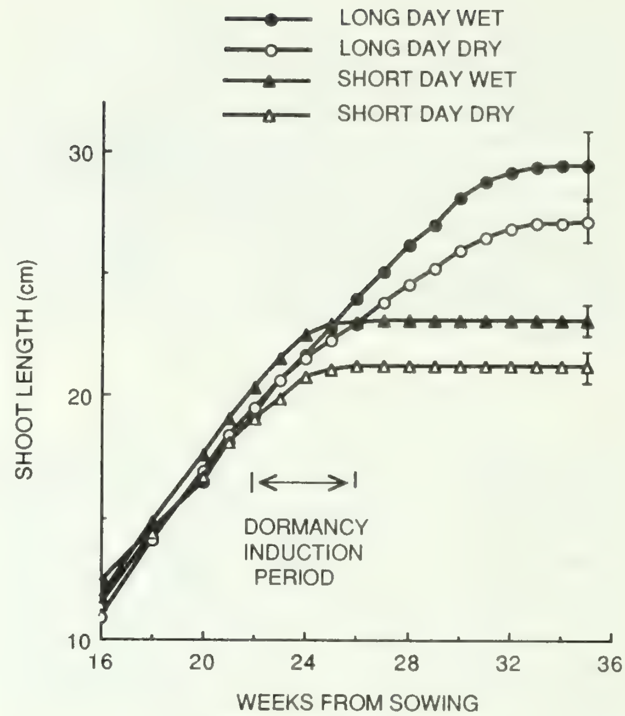

Figure 1.—Shoot length of western hemlock seedlings grown in the larger S4 container (PSB 415B) subjected to dormancy induction treatments, applied for 4 weeks beginning in mid-July (shown by the horizontal arrow). Vertical lines indicate ± 1 SE.

Seedling Physiology

Lifting date and length of cold storage had a highly significant (P<0.001) effect on RGC (table 2 and fig. 3). Container size and day length had a small, but significant effect, respectively; the larger S4 container and the short day treatments gave higher RGC (2.6 each) than the smaller cavity size and the longer days (RGC 2.4 each). For seedlings that were not cold-stored, RGC values increased significantly (P<0.01) between mid-November and mid-March. Seedling RGC values also significantly (P<0.01) increased with time in cold storage with the exception of the November-lifted stock that was stored for two months.

Later lifting dates and longer lengths of cold storage both significantly (P<0.001) increased DRI (fig.4). Some seedlings lifted in November (Lift 1) took more than 65 days to break bud resulting in a very low mean DRI value of 0.30. Those lifted in January (Lift 2) had lost a considerable amount of dormancy with a mean DRI value of 0.56 while those lifted in March (Lift 3) were fully released from dormancy with a DRI value of 1.00. While there were several significant treatment interactions

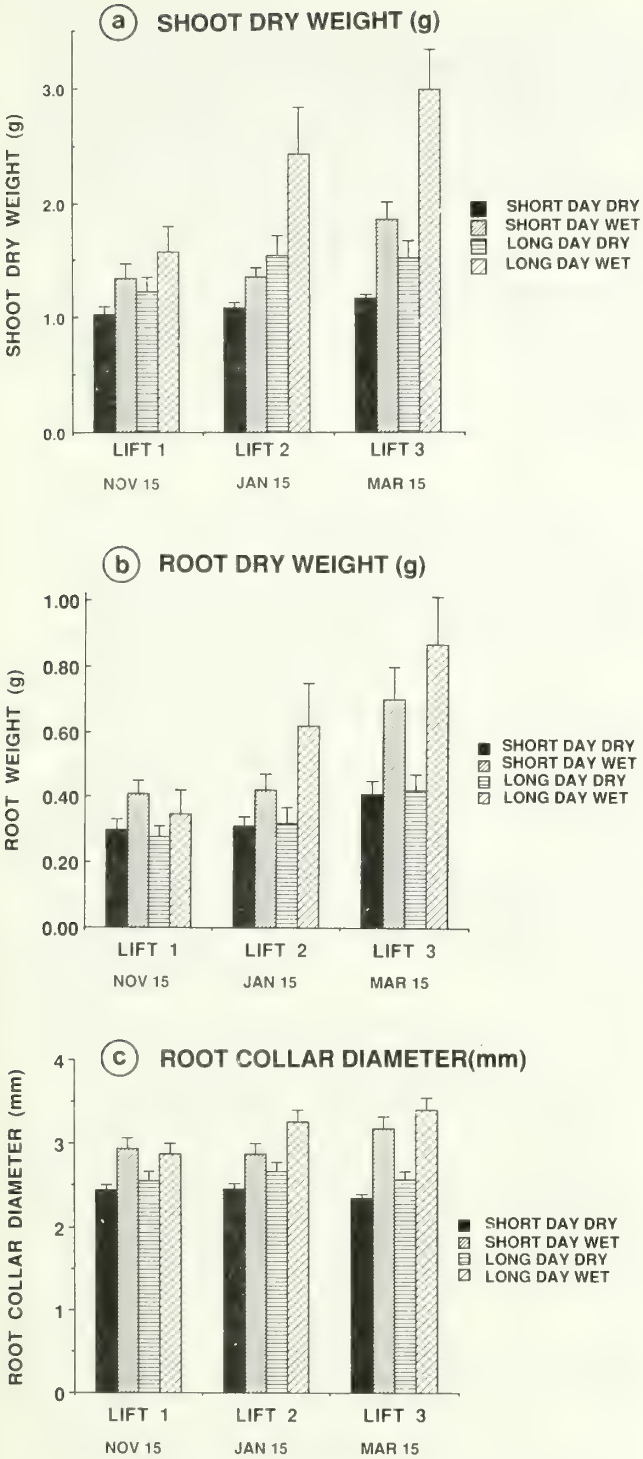

Figure 2.—Shoot dry weight (a), root dry weight (b) and root collar diameter (c) of western hemlock seedlings grown in the S4 container (PSB 415B) that had been subjected to four dormancy induction treatments (short day dry, short day wet, long day dry and long day wet) applied for 4 weeks beginning in mid-July, and three lifting dates (Nov. 15, Jan. 15, Mar. 15). Vertical lines indicate 1 SE within lifting dates.

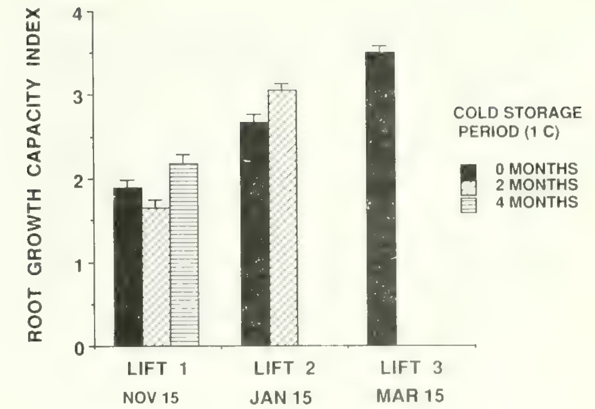

Figure 3.—Root growth capacity index of western hemlock seedlings for all treatment combinations lifted at three dates and cold stored for various lengths of time. Vertical lines represent 1 SE.

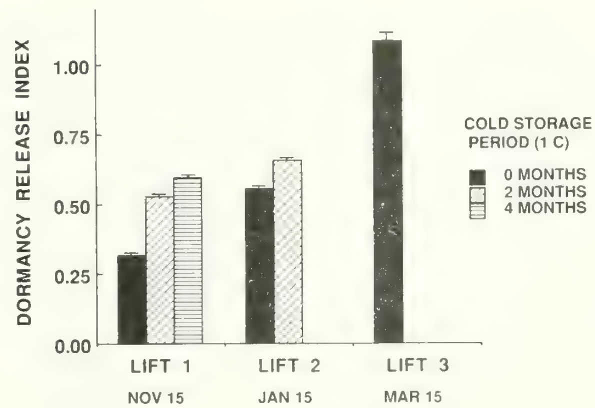

Figure 4. —Dormancy release index of western hemlock seedlings for all treatment combinations lifted at three dates and cold stored for various lengths of time. Vertical lines represent 1 SE.

(table 2) seedlings in the S3 containers had generally higher DRI values than those in the larger S4 containers and those seedlings subjected to short days had higher DRI values than those in the long day treatments. Moisture stress effects were also significant ($P<0.05$), an average of one day more being needed to break bud than in plants grown without moisture stress.

DISCUSSION

All treatment combinations in the nursery - container size, day length and degree of moisture stress - had a significant effect on seedling morphology. The larger container provided the seedlings with 80 % greater rooting volume and growing space. As a result, seedlings grown in the S4 container were taller (26 vs 24 cm), had greater

Table 2.—Anaylsis of variance summary of treatment effects on root growth capacity (RGC) and dormancy release index (DRI).

Treatment		RGC	DRI
Lift/Storage	(L)	***[1]	***
Container size	(S)	**	***
Daylength	(D)	*	***
Moisture	(M)	NS	*
C x L		NS	**
D x L		***	***
M x L		NS	NS
C x D		NS	NS
C x M		NS	NS
D x M		NS	***
C x D x M x L		NS	NS

[1]P<0.001 (***); <0.01 (**); <0.05 (*)

shoot dry weight (1.3 vs 0.8 g at Lift 1) and a larger root collar diameter (2.7 vs 2.2 mm at Lift 1) than those seedlings grown in the S3 container. As the effect of container size was so consistent throughout the study, it will not be discussed further .

Short days, applied in mid-July, rapidly arrested shoot elongation in western hemlock seedlings but moisture stress did not and, when used in combination with short days significantly reduced the number of needle primordia formed in the bud (O'Reilly et al. 1989a). Moisture stress also reduced shoot dry weight and stem diameter, most likely the result of reduced rates of photosynthesis caused by stomatal closure (Osonubi and Davies 1980). Moisture stress has been shown to produce terminal buds (Cheung 1973) and significantly reduce shoot growth of western hemlock seedlings (Cheung 1973; Nelson and Lavender 1976); unfortunately, the degree of moisture stress was not documented in these studies. In the present study, moisture stress (predawn average of -1.0 MPa) did not trigger bud development. In previous studies of other conifers (Lavender et al. 1968; Macey and Arnott 1986; Young and Hannover 1978), more severe stress levels have caused the formation of a terminal bud and arrested shoot elongation. Bud induction may require higher levels of moisture stress than those used in our study; however, this could result in mortality of western hemlock seedlings as they are sensitive to water stress. Some seedlings in our experiment died when predawn shoot water potentials decreased to -1.5 MPa.

Short days arrested shoot growth but did not result in a significant reallocation of dry matter to the roots as observed in pine seedlings (Ledig et al. 1970). Results similar to ours with western hemlock have been reported by Burdett and Yamamoto (1986) for Pinus contorta Dougl. and by Heide (1974) for Picea abies (L.) Karst.

Seedling quality assessment should be based on measurement of several physiological parameters (Ritchie 1984). In our experiment, we used RGC (Burdett 1979) and DRI (Ritchie 1984) to measure the impact of lifting date and cold storage duration on the seedling quality of western hemlock. The intensity of seedling dormancy weakened over the winter with DRI values rising consistently from mid-November (DRI= 0.3) to mid-March (DRI= 1.0). Western hemlock seedlings were released from dormancy at a slower rate in cold storage than those that were held in the nursery throughout the winter. Similer results were found for Douglas-fir and Ritchie et al. (1985) speculated that this was because (a) the temperature in cold storage (1°C) is below the optimum for dormancy release (4°C), (b) intermittent warm periods during the winter accelerates dormancy release and (c) absence of daily photoperiod may retard dormancy release in storage.

Subjecting seedlings to short day lengths in July to arrest height growth in the nursery will tend to result in an earlier release from dormancy in the next growing season; short day seedlings lifted in March flushed 2-3 days sooner than those grown under long days. This effect was enhanced by duration of cold storage. November-lifted seedlings under short day treatments flushed from 10 to 15 days sooner than those grown under long days. Using moisture stress as a means of controlling shoot growth in the nursery had a weakly significant (P<0.05) effect on the number of days it took the seedlings to break bud. Trees lifted in March that that been subjected to moisture stress flushed on average one day sooner than those grown under no moisture stress but considering the risk of mortality in western hemlock, the treatment is not recommended. In addition, seedlings planted in the spring that are predisposed to flush sooner stand a greater chance of being damaged by late-spring frosts.

RGC values were low for seedlings lifted in mid-November and gradually increased throughout the winter with later lifting dates. Similar observations have been made by D. Simpson (personal communication) for Picea glauca (Moench) Voss and by Mattson (1986) for Pinus silvestris L. In general, RGC values also rose while in cold storage, something also noted by Burdett and Simpson (1984) for Pinus contorta L. Therefore, a positive relationship exists between dormancy intensity and RGC in western hemlock seedlings. This is supported by the observation of consistently lower RGC and DRI values for seedlings that were cold stored versus those that remained in the greenhouse and were not stored. It is possible that the mechanisms controlling a seedling's RGC, DRI and chilling requirement are linked as suggested by Ritchie et al. (1985). Moisture stress during the growing season, had no significant effect on seedling RGC; short days resulted in a small, but significant increase.

CONCLUSION

The results of this study indicate that short days are the most effective method of controlling shoot growth of western hemlock seedlings in the nursery. Moisture

stress did not do this effectively and significantly reduced the final values for all morphological variables measured. In terms of seedling physiological quality as indicated by RGC and DRI values, the results indicate a preference for spring lifting of this species either immediately before planting in March or after two months of cold storage from a mid-January lifting date.

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Height Control of Interior Spruce by Means of Photoperiodic Induction[1]

C.D.B. Hawkins and D.A. Draper[2]

Abstract.--Four blackout periods were each applied for 3 durations to control height in interior spruce species at Red Rock Research Station (RRRS). In all six seedlots tested, height control could be achieved without significantly impacting end of season root collar diameter (caliper) or root mass. This finding is contrary to current nursery dogma. Evidence of physiological changes within treatment will be the basis for further studies at RRRS.

INTRODUCTION

In northern latitude nurseries the need to induce apical budset to limit height growth of spruce to desired standards is a recognized cultural challenge (Van Eerden, pers. comm. IX/87[3]). Often drought or nutrient stressing techniques (D'Aoust and Cameron 1981; Matthews 1981; Johnson 1985) are used, with the former the most common. However, drought stressing can have negative biological implications (Johnson 1985; MacDonald and Owens 1988), and height control through nutrient stress is not well understood in conifer crops.

An alternative to drought stressing may lie in blackout (photoperiodic induction of budset: Arnott and Mitchell 1981; Arnott 1982). In blackout treatments, the natural day length is artificially shortened prior to normal budset, thus simulating a later time in the growing season. This can result in cessation of height growth, apical budset and the initiation of frost hardiness/dormancy induction processes (Colombo et al. 1981).

The conventional photoperiod treatment in southern B.C. nurseries is to place seedlings in constant 8 h day 16 h night regimes on about 01 July for 4 weeks (Matthews 1983; MacDonald and Owens 1988). This results in budset but at the loss of potential photosynthate, especially at more northern latitudes. Another consequence of this treatment regime is the substantial difference betweeen treatment and ambient day length experienced by the plant upon removal from blackout. There can be as much as an 8 h increase to ambient day length

An alternative approach to constant night length for a given period of time is to develop photoperiod (PP) treatments which parallel the natural ephemeris at a particular nursery latitude. Thus while photoperiod is offset in terms of actual night hours, the treatment ratio of day to night length would parallel over time that of the ambient ephemeris (Figure 1). At RRRS, with treatment begining on 06 July (114 days after sowing), this results in dynamically increasing night lengths, rather than conventional static night length over the blackout treatment periods. The experimental advantages to this dynamic treatment approach are; constant difference between a given blackout treatment and ambient day length at the conclusion of all treatment durations, increased use of northern latitude long days, and inclusion of ambient ephemeris conditions as a formal 'control' level in treatment comparisons.

This study reports on the use of dynamic blackout regimes for height control of interior spruce.

METHODS

Six spruce seedlots (Table 1) were sown on 14 March 1988 into BCFS/CFS 313[B] polystyro blocks (764 cavities m^{-2}) containing a 2 parts peat, 1

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[1] Poster presented at Combined, Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; Vernon, B.C., August 8-11, 1988.

[2] Research Scientists, British Columbia Ministry of Forests, B. C. Forest Service, Research Branch, Red Rock Research Station, RR#7, RMD 6, Prince George, B.C. V2N 2J5 Canada.

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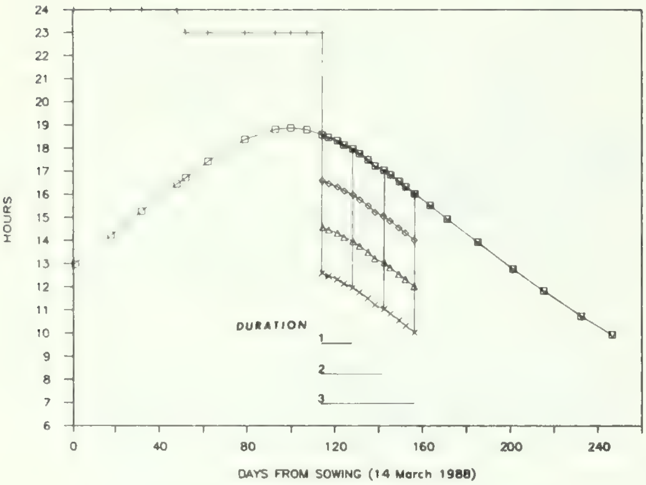

Figure 1.--The ephemeris (natural day length + civil twilight) at RRRS (latitude 53°45' N, longitude 122°41' W), ☐, showing the blackout treatment regimes tested. Photoperiod applied to crop prior to blackout treatment, (+); 17 h (◇), 15 h (△), and 13 h (X) photoperiods during 2, 4 or 6 weeks of blackout D1, D2 or D3, respectively; and ambient photoperiod during and after blackout application (☒).

part vermiculite growing media. Gypsum and 12 mesh lime were added to the media at rates of 1.0 and 0.9 kg m^{-3}, respectively. Germination was carried out in Harnois[4] greenhouses as described by Hawkins and Draper (1988) equiped with a reflective outer cloth (Enershade® LS11, 95% blockage) and an inner black absorbent cloth (Enershade® 100 S/B, 100% blockage) blackout system[5]. Thermal regimes were 20° C for 5 days and then 20/11° C for 13/11 h, day/night for 4 weeks. Five weeks after sowing a 20-8-20[6] fertilizer regime modified from Draper and Hawkins (1988) was applied to the crop at a rate of 60 ppm N[7]. Heating setpoints[8] were changed to 19/13° C for 16/8 h, day/night at this time. All greenhouse and blackout systems were controlled with an ESC 2000[9] computer system.

All stock was grown under continuous photoperiod until 6 May, then it was growm under a 23 h photoperiod until blackout treatments were initiated on 6 July 1988. Four blackout treatments were chosen (Figure 1), ambient (nominal 19 h) nominal 17 h, 15 h, and 13 h photoperiods. Each was applied for 2, 4 and 6 weeks duration. Times of blackout were changed daily and curtains were closed at the desired evening time, opened after civil sunset, closed again prior to civil sunrise, and opened at the desired time in the morning. The extra opening was to facilitate humidity regulation. At the end of each blackout treatment, stock was returned to ambient photoperiod and grown under it until lifing and storage in early November.

Analyses that have been or will be carried out on these treatments[10] include seasonal serial height determinations; seedling morphology (height, caliper, root and shoot masses) over the season; timing of frost hardiness and dormancy induction processes; developmental anatomy of buds for all treatments in one seedlot; post-cold storage phenology including LT_{50}[11] assessments; mitotic indices; farm-field outplantings; and planting of all seedlots back in location of origin.

RESULTS

Due to the complexity of this trial (72 treatments) and because similar treatment

Table 1.--Seedlot (SL), species (SPP), and approximate elevation (ELEV), latitude (LAT) and longitude (LONG) of origin of the stock.

SL[1]	SPP[2]	ELEV m	LAT °N	LONG °W
5261	Se	1650	49°20	119°30'
4311	Se	1435	50°50	120°30'
8482	Se	1140	52°15	120°30'
599[3]	Sw	760	54°20	125°30'
8779	Sw	1067	55°45'	122°30'
3958	Sxs	400	55°00'	128°45'

[1] British Columbia Forest Service (BCFS) registered seedlot number.

[2] Species abbreviations: Se, Picea engelmannii Parry; Sw, P. glauca (Moench) Voss; Sxs, P. glauca and its naturally occurring hybrid with P. sitchensis (Bong.) Carr.

[3] Courtesy of G. Kiss of the BCFS interior spruce tree improvement programme.

[4] R: mention of a trademark name, proprietary product or firm does not imply recommendation by the B.C. Forest Service to the exclusion of others in the market place.

[5] Supplied by Van Rijn Enterprises Ltd., Stoney Creek, ON, L8E 4C3 Canada

[6] 20-8-20 "Forest Seedling Special" supplemented with "Plant-Prod" Chelated Trace Element Mix (both from Plant Products Fertilizer Ltd., Bramalea, Ont., L6T 1G6), solubor and $CuSo_4$ at rates of 40.0, 1.2, 0.08 and 0.02 g l^{-1} of stock solution, respectively.

[7] N application increased to 90 ppm in early July and gradually reduced to 30 ppm by early October.

[8] This setpoint maintained until 20 July when setpoints were gradually lowered, to assist in frost hardiness / dormancy induction processes, reaching 9/1° C for 11/13 h day/night on 26 Oct.

[9] Energrated System Consultants Ltd., Surrey, BC V3W 8V3 Canada.

[10] 4 photoperiods X 3 durations X 6 seedlots = 72 treatments.

[11] Temperature required to damage 50% of the seedlings in a given phenological class.

responses were observed for all seedlots, results (one month prior to lifting) are presented for one seedlot (3958).

Serial height increments are presented for all photoperiods (PP) at 2, 4 and 6 weeks duration (Figure 2). Only the 13 h PP was effective for height control after 2 weeks of application (Figure 2a), whereas both 13 and 15 h treatments were effective after 4 and 6 weeks application.

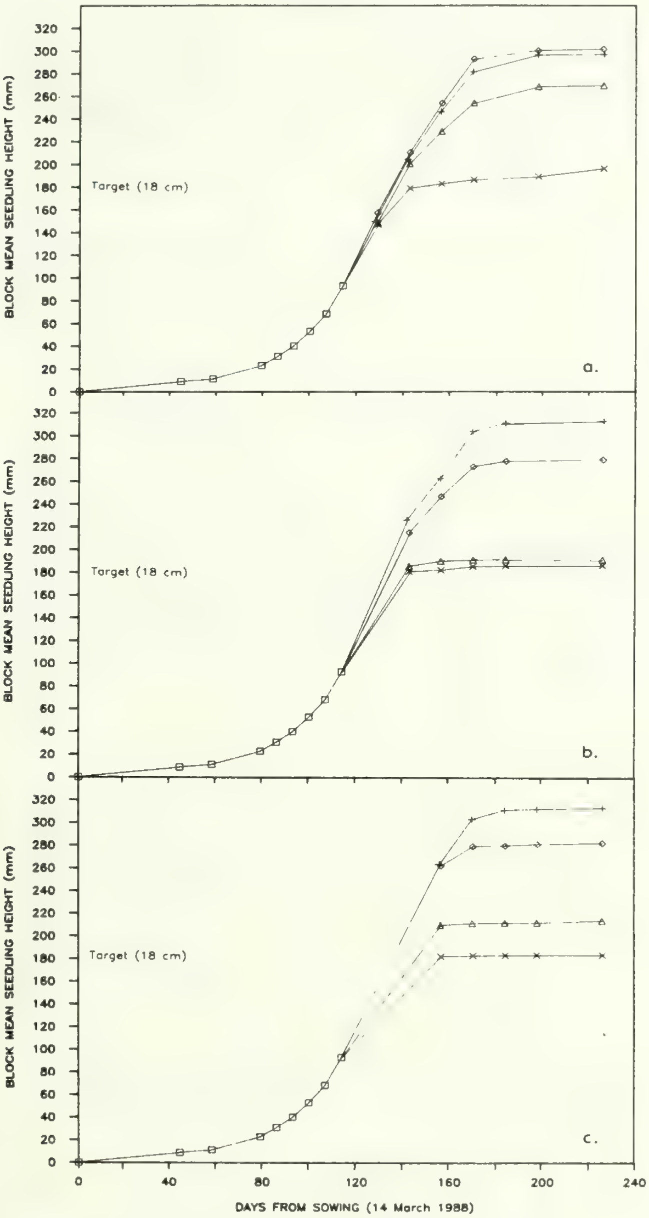

Figure 2.--Cummulative mean seedling block height (based on a serial sample of 10 seedlings from each of six blocks) for seedlot 3958.
a) all PP applied for 2 weeks (D1);
b) all PP applied for 4 weeks (D2); and
c) all PP applied for 6 weeks (D3).
Pre-blackout ambient (⊠), nominal 19 h (+), 17 h (Ø), 15 h (△), and 13 h (X) photoperiod treatments.

Table 2.--Seedlot 3958 (Sxs) treatment (P D) mean[1] and standard error (SE) of caliper (root collar diameter), shoot (SDW) and root (RDW) dry weights, and shoot to root ratio (S:R) six weeks after removal of the longest durations from blackout.

P[2]	D weeks		Caliper mm	SDW mg	RDW mg	S:R
13	2		3.52	1593	572	2.78
		SE	0.115	126.4	28.6	nc[3]
13	4		3.33	1450	620	2.34
		SE	0.156	139.7	91.8	nc
13	6		2.56	1270	560	2.27
		SE	0.115	93.3	76.3	nc
15	2		3.29	1989	445	4.47
		SE	0.212	261.4	79.3	nc
15	4		2.95	1361	485	2.81
		SE	0.222	129.4	26.8	nc
15	6		3.01	1528	567	2.69
		SE	0.173	110.4	64.0	nc
17	2		3.33	2236	492	4.54
		SE	0.112	187.0	59.4	nc
17	4		3.04	1681	366	4.59
		SE	0.198	118.8	44.4	nc
17	6		3.38	2080	503	4.14
		SE	0.146	167.7	39.0	nc
19	2		3.31	2084	503	4.14
		SE	0.179	172.0	63.5	nc
19	4		3.28	2023	385	5.25
		SE	0.154	187.5	40.3	nc
19	6		3.15	1918	392	4.89
		SE	0.107	142.3	55.8	nc

[1] Each mean is from a random sample of 18 seedlings.

[2] Photoperiods (P): nominal 13 h, P1; nominal 15 h, P2; nominal 17 h, P3; and nominal 19 h (ambient), P4. Durations (D): 2 weeks, D1; 4 weeks, D2; and 6 weeks, D3. All blackout periods were followed by a common ambient light regime.

[3] nc, not calculated.

Seedling caliper was reduced by 13 h PP applied for 6 weeks (Table 2). Root dry weight was similar between photoperiod treatments but shoot dry weight was reduced by shorter photoperiods (Table 2). Shoot to root ratios varied but generally were largest in the longer photoperiod treatments (Table 2).

Foliage frost hardiness occurred soonest in the shortest photoperiod applied for the longest duration[12]. Seedlot was also important in

[12] Assessed using the -18° C test. Stock is held at +3° C for 1 h, cooled to -18° C at 6° C h^{-1}, held at -18° C for 1 h, ramped to 3° C at 6° C h^{-1}, held at 3° C for 1 h, and then placed in a standard environment (30/25° C, 16/8 h, day/night, RH 75%, and light intensity of 500 µmols) for 1 week and then evaluated.

determining frost tolerance because the more northerly the origin of the seedlot, the sooner it achieved frost hardiness (not presented). The Sxs seedlot was the last to attain foliage frost hardiness.

DISCUSSION

For this vigorous hybrid seedlot, little or no height control was achieved with longer PP treatments, regardless of the duration of their application (Figure 2). However, adequate height control was achieved with minimal impact on the other variables using the shorter, but still relatively long, PP treatments.

Two weeks of nominal 13 h PP treatment resulted in control about target heights, with associated good caliper and plant mass relationships (Figure 2a, Table 2). This treatment however, produced considerable lateral lammas growth in September (not presented) indicating that it is not a suitable treatment at this latitude.

Application of blackout for four weeks at nominal 13 h or 15 h PP resulted in good control of height about desired targets, with acceptable caliper and plant mass relationships (Figure 2b, Table 2). Based on this preliminary data, it appears that four weeks of nominal 13 h PP resulted in better quality nursery stock. There was no lammas growth with either of these treatments. The 13 h PP stock also achieved frost hardiness earlier than did the 15 h PP stock. The longest application of blackout for the nominal 13 h or 15 h PP also achieved the desired control of height but caliper was much reduced for stock from the shortest PP treatment (Figure 2c, Table 2). Again, there was no lammas growth.

As blackout installation is expensive, there often is a desire by nurserymen to get more than one crop rotation through a blackout equipped house. Therefore, the shortest duration which achieves the desired nursery results is the most attractive. In this case, it is probably four weeks of 13 h PP.

The greater root masses observed under the longer blackout treatments (Table 2) are a result of a rapid and major shift in carbon allocation to the roots, about two weeks after the onset of blackout (not presented). This presumedly occurs because of the changes in plant growth substance concentrations associated with the induction of terminal budset. There is a slowing in the rate of root mass increase for stock from the shorter PP treatments as frost hardiness increases. This is probably a result of decreased rates of photosynthesis during the period of increasing frost hardiness in spruce (Hawkins et al. pers. comm. III/87[13]). Based on projections at this time, there will be little difference in root mass between treatments at the time of lifting and storage, while the large differences in shoot mass will remain.

The blackout treatments which are most appealing in this study are the longest ones. However, these nominal 15 h and 13 h day treatments induce responses that are to be expected from much shorter conventional static 8 h or 10 h days (Hawkins and Hooge[14], table 1). It appears that the dynamic approach used in this study enhanced seedling response to shortened days. Perhaps, seedlings not only respond to the absolute day length but to the rate at which the day length is changing, i.e. the 'dynamic day'.

The best dynamic blackout treatments have resulted in stock which is in balance (shoot:root ratios), has good root mass, has achieved early frost hardiness, and has adequate time for dormancy induction processes. These results run counter to traditional local nursery belief which suggests that blackout treatments result in seedlings with inadequate root mass and insufficient caliper.

Regardless of what the stock looks like at the nursery gate, the potential liabilities presented at these meetings[14,15] of stock grown under blackout must be kept in mind. That is, the accelerated spring flush and the delayed fall budset. Therefore, the nursery treatment cannot be fully evaluated until after early field assessments are in.

ACKNOWLEDGEMENTS

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Heating System, Germination Temperature and Post Germination Fertilizer Regime Effects on White Spruce Nursery Growth[1]

C.D.B. Hawkins,[2] D.A. Draper,[2] and R.Y.N. Eng[3]

Abstract.--Morphology of white spruce 1-0 seedlings grown with under-bench heating did not differ from those grown with over-bench heating. No differences were observed between 20/11°C (12/12 h, day/night) germinated seedlings and 20/20°C germinated seedlings, although the heating costs of the latter were almost double. Fertilization with N-P-K 20-8-20 produced shorter seedlings with greater root mass than a 20-20-20 plus 10-52-17 fertilizer regime.

INTRODUCTION

The accelerated rate of backlog reforestation programs in north central British Columbia challenge northern latitude nurseries to develop cultural techniques for the production of cost-effective and high performance seedlings. Research specific to northern latitude container seedling production is relatively scarce. Major concerns of northern growers are heating costs during the March to April germination period, crop height control and achieving adequate root mass at harvest.

This report describes trials carried out at Red Rock Research Station (RRRS), located near Prince George, B.C. (Lat. 53°45'N, Long. 122°41'W), to evaluate the effect of:

1. germination temperature setpoints and greenhouse heating systems on the energy costs and morphological development of white spruce, and

2. the effect of two fertilizer regimes on crop morphological development.

METHODS

A white spruce (Picea glauca (Moench) Voss) 1-0 container crop was sown on March 18, 1987 in BCFS/CFS styroblock 313a in a mixture of 2 peat moss : 1 vermiculite, incorporating Osmocote(R) (18-6-12) and 12 mesh lime at 6.5 and 2.0 kg m^{-3}, respectively. Three treatments, combining air temperature setpoints and greenhouse heating systems, were tested for five weeks beginning on 18 March 1987:

1. 20/20°C[4] with over-bench forced air heating
2. 20/20°C[4] with unskirted under-bench forced air heating
3. 20/11°C[5] with unskirted under-bench forced air heating

Block soil temperature averaged 2° C lower than air temperature setpoints. At the end of the five week germination period, all three temperature regimes were changed to 20/13°C[6], and were gradually lowered over the growing season to harden the plants for harvest on November 2.

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[1]Poster presented at Combined Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; 1988 August 8-11; Vernon, B.C.

[2]Research Scientists and
[3]Research Officer, British Columbia Ministry of Forests, Research Branch, 31 Bastion Square, Victoria, B.C. V8W 3E7 Canada

[4]20/20°C = 24 h at 20°C air temperature setpoint

[5]20/11°C = 12 h at 20°C air temperature setpoint from 0800 h to 2000 h (day) and 12 h at 11°C air temperature setpoint from 2000 h to 0800 h (night)

[6]20/13°C = 16 h at 20°C air temperature setpoint from 0600 h to 2200 h (day) and 8 h at 13°C air temperature setpoint from 2200 h to 0600 h (night)

Table 1.--Description of experimental treatments by germination air temperature[1], heating system[2] and fertilizer regime[3]. *A priori* contrasts are specified within the 5 treatments.

		Treatments				
Contrast	df[4]	20/20°C under-bench 20-20-20	20/20°C over-bench 20-20-20	20/20°C under-bench 20-8-20	20/20°C over-bench 20-8-20	20/11°C under-bench 20-20-20
Germination Temperature Effect	1	1	0	0	0	-1
Heating System Effect at 20/20°C	1	1	-1	0	0	0
Fertilizer Effect[5]	1	1	1	-1	-1	0
Heating Fertilizer Effect[5]	1	1	-1	1	-1	0
Heating by Fertilizer Interaction[5]	1	1	-1	-1	1	0

[1]Germination air temperature: 20/20°C or 20/11°C
[2]Heating system: under-bench or over-bench
[3]Fertilization regime: 20-20-20 or 20-8-20
[4]Degrees of freedom
[5]Contrasts are orthogonal within themselves

Following the germination period, two fertilizer treatments were applied to the 20/20° C temperature treatment germinants:

1. 20-8-20[7] formulation applied for the remainder of the season

2. 20-20-20[8] formulation applied until July 24, followed by 10-52-17[9] formulation until harvest

Both fertilizer regimes were applied at 120 ppm-N until June 11, at 60 ppm-N June 11-Aug 17, and at 50 ppm-N Aug 17-Nov 2. On August 17, each fertilizer treatment was supplemented with a trace element package[10] at 0.75 g l^{-1} of stock solution until harvest on November 2, at which time the seedlings were freezer stored until April 15 when thawing at 5° C was initiated for spring planting on 19 May.

[7]"Forest Seedling Special", Plant Products Fertilizer Ltd., Bramalea, Ontario Z6T 1G1

[8]"Hi-Sol", Green Valley Fertilizers Ltd., Surrey, B.C. V3W 3A8

[9]"Plant Starter", Green Valley Fertilizers Ltd., Surrey, B.C. V3W 3A8

[10] "Plant-Prod Chelated Trace Element Mix", Plant Products Fertilizer Ltd., Bramalea, Ontario Z6T 1G1

Experimental treatments are listed in table 1 with statistical contrasts of interest specified.

RESULTS

Heater running time during germination and hence direct energy consumption costs, were reduced by almost 50 percent using the 20/11° C germination temperature treatment (Fig. 1).

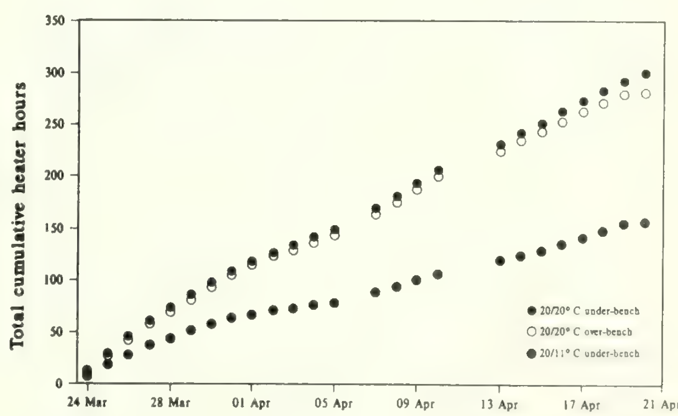

Figure 1.--Greenhouse heater run-time totals during the 1987 germination period.

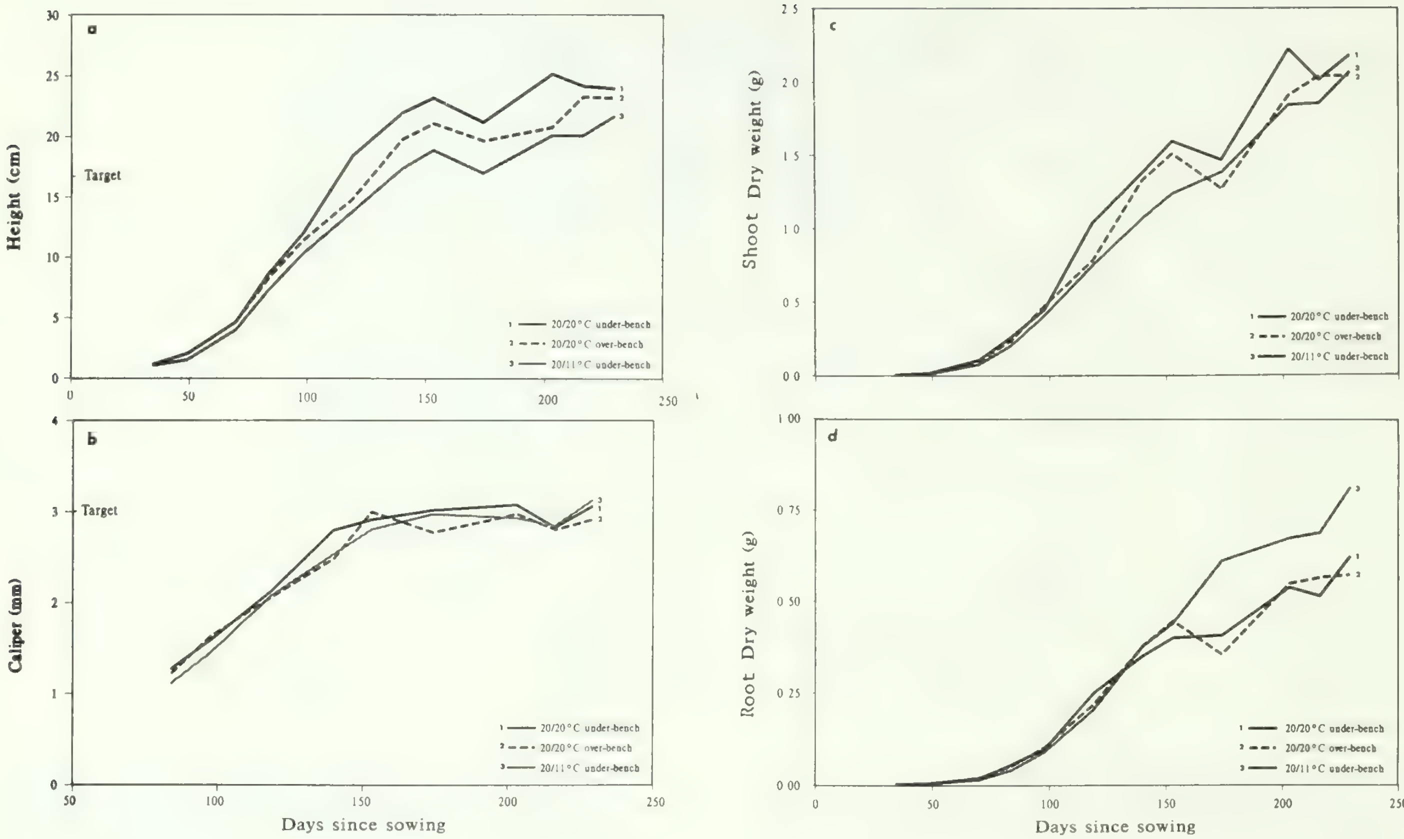

Figure 2.--Cumulative mean height (a), caliper (b), shoot dry weight (c), and root dry weight (d) of white spruce. Values the mean of 20 seedlings.

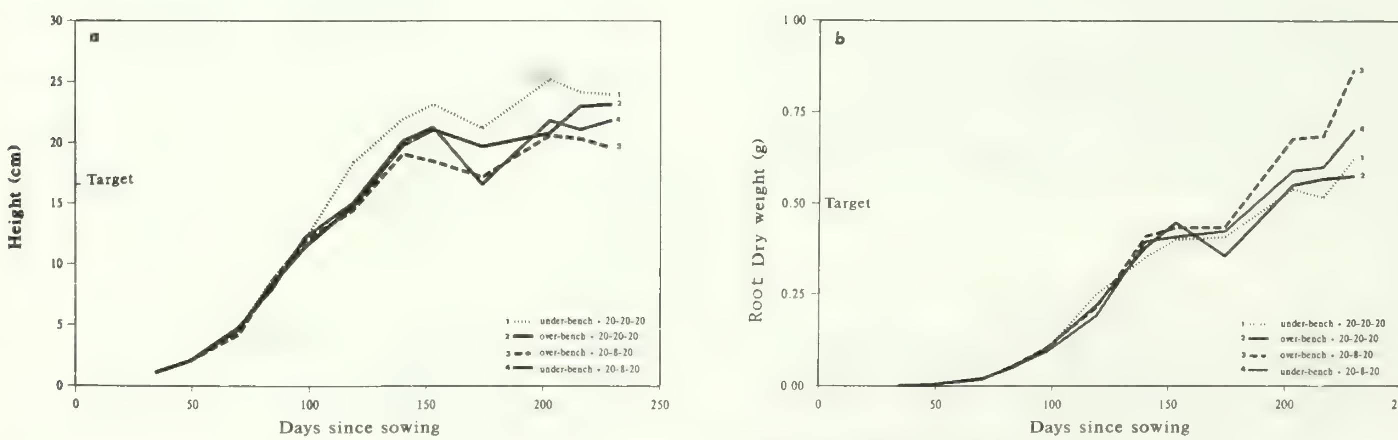

Figure 3.--Cumulative mean height (a), and root dry weight (b) of white spruce. Values the mean of 20 seedlings.

Table 2.--Specified contrast F value and probability of F occurring by chance (bracketed), by morphological variable at end of season.

Contrast	Height (cm)	Caliper (cm)	Shoot Dry Weight (g)	Root Dry Weight (g)
Germination Temperature	1.60 (0.21)	0.24 (0.63)	0.20 (0.65)	2.92 (0.09)
Heating System Effect at 20/20°C	0.20 (0.66)	0.84 (0.36)	0.24 (0.63)	0.20 (0.65)
Fertilizer[1]	5.28 (0.02)	1.86 (0.18)	0.48 (0.49)	5.65 (0.02)
Heating[1] System	1.41 (0.24)	0.27 (0.61)	0.27 (0.61)	0.57 (0.45)
F x HS[2] Interaction[1]	0.29 (0.59)	0.63 (0.43)	0.06 (0.80)	1.85 (0.18)

[1]Signifies contrasts are orthogonal within themselves.
[2]Fertilizer x Heating System

There were no practically significant differences in total heater hours between over- and under-bench heating systems during the germination period (Fig. 1). Expected cost saving with under-bench heating may not have been realized because benches were not skirted.

There were no significant difference in final seedling height, caliper (root collar diameter), root or shoot dry weight at harvest for either germination temperature regime or heating system (Fig. 2 and Table 2). There was no difference in seedling recovery to height and caliper specifications among treatments.

Seedlings in the 20-8-20 fertilizer regime had significantly decreased heights and increased root masses compared to the 20-20-20 regime (Fig. 3 and Table 2). Shoot mass and caliper were not affected by fertilizer treatment (Table 2).

CONCLUSIONS

Heating costs in this study were reduced with the 20/11°C treatment during the germination period without significantly affecting seedling morphology or seedling numbers recovered to height and caliper specifications at harvest.

Significantly shorter seedlings with larger root masses were produced with the 20-8-20 fertilizer regime. Fertilizer regime differences may have been reduced by nutrient available in the Osmocote supplemented growing media.

Results from seedling assessment after one growing season in a farm field environment indicate no nursery treatment differences in survival and performance.

The results from 1987, an excellent growing year, have not been confirmed operationally over a number of growing seasons. Until stock produced via new cultural regimes is field tested, it has no place in operational practices. The goal of forest regeneration is not to produce stock that "looks good" in the nursery but to produce stock that performs well in the field.

ACKNOWLEDGEMENTS

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Blackout and Post Planting Bud Phenology in SxS Spruce Seedlings[1]

C.D.B. Hawkins[2] and B.D. Hooge[3]

Abstract.--Spruce stock grown under three blackout regimes in 1987 was cold stored over the winter and farm-field planted in May 1988. Blackout treatment did not affect root egress but the longest blackout treatment resulted in earlier spring flush, later fall bud set, and increased the susceptibility of seedlings to freezing temperatures.

INTRODUCTION

Sxs spruce (Picea glauca (Moench) Voss and its naturally occurring hybrid with P. sitchensis (Bong.) Carr.) displays typical hybrid vigor making the control of its height growth in the nursery quite difficult. Usually moderate moisture and/or nutrient stress (Macey and Arnott 1986) is used to control height in this species. However, these techniques can have negative biological side effects (Johnson 1985).

Photoperiodic induction of bud set does result in cessation of height growth in spruce (Colombo et al. 1981) and in Sxs it can be an effective means of height control (Table 1). However, Colombo, Odlum and co-workers[4,5] have observed that buds initiated under shortened photoperiods (PP) resulted in shoots which grew four weeks later into the year than did shoots from buds which had been initiated under ambient PP. Prolonged growth, such as this, has the potential to delay frost hardiness/dormancy induction processes, and with it, increase the probability of early fall and/or winter low temperature damage.

The effect(s) of nursery blackout regimes on the first farm-field season bud phenology of Sxs spruce is described here.

METHODS

Sxs stock was germinated in an under bench heated 20° C greenhouse and was raised using thermal and 20-20-20 fertilizer regimes as described by Hawkins et al[6]. Three levels of blackout (as described in table 1) were applied in growth chambers for five weeks commencing on 15 July 1987. After blackout treatment, stock was grown under ambient photoperiod in a greenhouse until lifting and storage on 02 November 1987. The stock was planted in a farm-field[7] at Red Rock Research Station (lat. 53°45' N; long. 122°41' W) on 19 May 1988.

The total number of new roots produced greater than one cm and the average number of days to flush in a growth chamber were determined. As well, the total number of new roots (≥ 1 cm) produced 26 days after farm-field planting was assessed.

Bud phenology was assessed, using a

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[1] Poster presented at Combined, Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; Vernon, B.C., August 8-11, 1988.

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[4] S.J. Colombo, K.D. Odlum and C. Glerum. 1986. Measuring and improving the pysiological quality of planting stock. Stock Production Development Activity Seminar, December 1-4, 1986. Timmins, Ontario.

[5] Odlum, K.D. and S.J. Colombo. 1988. Short day exposure to induce budset prolongs shoot growth in the following year. Paper presented at these meetings.

[6] Hawkins, C.D.B., D.A. Draper and R.Y.N. Eng. 1988. Heating system, germination .... fertilizer effects on white spruce nursery growth. Poster presented at these meetings.

[7] 4 blocks each containing 24 seedlings were planted for each treatment.

subjective scale (see table 2), at weekly intervals for the first six weeks after planting and then at approximate fortnightly periods until early November 1988.

RESULTS AND DISCUSSION

The relationship between treatments for the total number of new roots produced (≥ 1 cm) was not the same for growth chamber and field assessments (table 2). This is probably a response to the different soil temperatures for the two determinations. However, under both conditions, new root production was very good. The lowest IRG (Burdett 1979) was 4 for the ambient stock tested in the growth chamber, and 5 for all other treatments.

The average number of days to flush in the growth chamber was greatest in the ambient treatment and least in the 10 h PP treatment (Table 2). This suggests that not only may seedlings grown under blackout regimes have altered fall phenology as reported by Colombo et al.[4,5], but spring phenology also may be altered. The earlier flushing observed for blackout treated stock could predispose it to damage by late spring frosts.

Twenty-two days after planting, 85% of the 10 h PP seedlings had elongating leaders while only 26% of the ambient PP trees were flushing (table 3). Again, the rate of flush of the blackout treated seedlings could increase the occurrence of spring frost damage. However, one week later, all the stock was flushing (table 3, day 28), indicating that the potential window of enhanced damage for the 10 h and 12 h PP treatment stock was not appreciably longer than for ambient PP seedlings.

Table 1.--End of season (02 November 1987) mean morphological measurements[1] and standard error (SE) for height (Ht), caliper (Cal), root (RDW) and shoot dry weights (SDW) of Sxs grown under blackout[2] for 5 weeks[3] and then returned to ambient photoperiod until lifting and storage.

PP	Ht	Cal	RDW	SDW
	cm	mm	mg	mg
Ambient	29.8	3.63	600	2378
SE	1.0	0.14	57	151
12 h	24.1	3.20	620	1930
SE	0.8	0.15	70	152
10 h	20.1	2.50	450	1458
SE	0.5	0.10	38	107

[1] B.C. Forest Service stock standards for Sxs are: Ht, min/target/max, 14/18/30 cm; Cal, min/target, 2.2/2.6 mm; and RDW, min/target, 500/700 mg. There are no mass standards for the shoot. Each measurement is the mean of 20 trees.

[2] Three blackout treatments applied on 15 July 1987 were: ambient PP, natural day length decreasing from 18:19 h to 16:01 h over the 5 weeks; 12 h constant and 10 h constant PP both applied for 5 weeks.

[3] All stock exceeded minimum height when blackout was applied.

Table 2.--Mean[1] and standard error (SE) of the total number of roots produced (≥ 1 cm) after one week in the growth chamber[2] (GC), 26 days after field planting (AP), and the mean number of days to flush (TF) in a growth chamber for the three photoperiod treatments[3].

PP	Roots ≥ 1 cm		TF
	GC	AP	days
Ambient	20.1	76.9	16.8
SE	4.2	8.4	1.3
12 h	59.9	60.9	10.9
SE	3.5	12.9	0.6
10 h	32.3	45.7	8.4
SE	4.3	4.3	0.3

[1] Each measurement is the mean of 16 seedlings.

[2] In growth chamber at 30/25° C, 16/8 h, day/night, RH 75%, light intensity 500 µ mols for one week; standard BCFS RGC conditions.

[3] See table 1 for treatment descriptions.

Blackout treated stock flushed sooner and continued leader elongation later into the season (table 3, day 112) than did stock from the ambient treatment. On 17 September (day 121), there was a near record low temperature of -6.9° C. This apparently resulted in considerable mortality of terminal buds in the 10 h PP treatment seedlings (table 3, day 137). The altered and presumedly delayed phenology observed in the 10 h PP treatment resulted in the increased mortality following exposure to fall frosts for this treatment. The response of the 12 h PP stock was intermediate between the other two treatments (table 3). On days 135 and 172 this treatment responded more like the ambient treatment than the 10 h PP treatment stock, whereas, very early in the season it responded more like 10 h PP stock (table 2, TF). This suggests that a reacclimation (towards ambient) is possible.

By the time of the last assessment, more than one-third of the trees in the 10 h PP treatment had dead terminal buds and all seedlings with surviving terminal buds were in bud class 5 (table 3, day 172). In just over one month, bud mortality in the 10 h PP stock increased from 25 to 35 percent, indicating the severity of damage to this treatment. However, seedling survival was 100% for all treatments at this time.

The time available for frost hardiness and dormancy induction processes was likely much less in the blackout treated seedlings because of their growing later into the season, and their delay in initiating terminal buds as indicated by

Table 3.--The total number of seedlings, as a percentage, in a given subjective bud class[1] on each sample day in the 1988 farm-field outplanting at RRRS for Sxs spruce subjected to ambient (A), 12 h (12), or 10 h (10) photoperiod treatments (PPT) for five weeks in the nursery during 1987.

Day[2]	Percentage of trees in each bud class																				
	0			1			2			3			4			5			D		
	PPT			PPT			PPT			PPT			PPT			PPT			PPT		
	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10
0	100	100	100[3]																		
11	69	52	16	31	48	84															
22	1	0	1	63	30	14	36	70	85												
28				3	0	0	97	100	100												
54							7	1	0	93	99	100									
96							1	0	1	99	100	99									
112										39	61	79	61	39	21						
137													80	77	70	14	13	5	6	10	25
172																92	86	65	8	14	35

[1] The subjective bud classes are:
Class 0, resting spring terminal bud;
Class 1, swelling terminal bud;
Class 2, flushing (elongating) leader;
Class 3, lateral buds visible on leader;
Class 4, terminal bud scales, bud filling;
Class 5, resting fall terminal bud; and
Class D, dead terminal bud, frost killed.

[2] Days since planting on 19 May 1988, for brevity and clarity, not all sample days are shown.

[3] 84 seedlings were sampled for each treatment

increased bud mortaility. There is a distinct possibility that the 10 h PP seedlings will also undergo considerable winter damage when compared to the other treatments because of the shorter time available for completion of their frost hardiness and dormancy induction processes prior to winter. However, this will not be known until spring 1989 assessments.

CONCLUSIONS

Blackout of Sxs does alter seasonal bud phenology both in the spring and the fall of the following growing season. Stock from shorter day length treatments is placed at greater risk to frost injury in the fall because of the longer fall damage window duration. The duration of altered phenology induced by the blackout treatments is yet to be determined. It appears that stock from the intermediate treatment can reacclimate towards responses more typical of control stock, while stock from the longest PP treatment changes little. If the effect lasts into the second field season it could have a significant impact on seedling form and growth and plantation form and survival.

The present data set does not preclude the use of blackout for height control. A morphologically acceptable seedling was produced from an intermediate blackout treatment which, while altering seedling phenology, did not result in bud damage significantly different from control stock. Therefore, it is reasonable to assume that a compromise can be achieved between blackout period and duration, nursery stock standards, and early field phenological response.

Acknowledgements

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Short Day Exposure to Induce Budset Prolongs Shoot Growth in the Following Year[1]

Kerry D. Odlum and Stephen J. Colombo[2]

Abstract.--Short day exposure applied in the greenhouse prior to overwintering container black spruce (Picea mariana [Mill.] B.S.P.) seedlings dramatically influenced the timing and duration of shoot growth in the first year after outplanting. When compared with seedlings grown under natural daylength bud initiation regimes in the year prior to planting, short daylength seedlings flushed sooner in the spring and set bud later at the end of the growing season, resulting in greater shoot growth. The extended duration of shoot growth in SD seedlings is expected to place them at greater risk of damage from both late spring and early fall frosts.

INTRODUCTION

Conifer seedling response to photoperiod has been studied a great deal since early work by Kramer (1936) and is well reviewed by Arnott and Mitchell (1982) and Lavender (1980). In spruce, terminal buds are induced under short daylengths while vegetative shoot growth continues under long days (Dormling et al. 1968). This knowledge is necessary for nurserymen to successfully grow spruce seedlings in a greenhouse. When height growth is needed in a crop, it can be ensured, regardless of the natural daylength, by artificially extending the daylength within the greenhouse or by interrupting the dark period during the night (Arnott 1974). Similarly, by shortening the daylength within the greenhouse a nursery manager can rapidly and uniformly terminate shoot growth and induce budset in his crop at any time of year.

Because of the greater control in production schedules afforded by the use of short daylength exposure, the procedure is now routinely applied in black spruce (Picea mariana [Mill.] B.S.P.) production at approximately 30% of all container seedling nurseries in Ontario.

Daylength treatments applied in the greenhouse are known to influence the timing and/or growth of seedlings the year following treatment, depending upon species (Arnott and Macey 1985, Heide 1974). The objective of this study was to determine whether similar after-effects occur with black spruce seedlings that have set bud under short daylengths in operational greenhouse production.

MATERIALS AND METHODS

Seedlings used in this study were grown operationally in 1986 at a greenhouse nursery near Englehart, Ontario (47°49'N, 94°55'W) where both natural daylength (ND) and short daylength (SD) bud initiation regimes were applied. Seedlings of a site region 3E (Hills 1960) seed source were grown using a schedule similar to that of Carlson (1983) with the exception of bud initiation regimes which are summarized in table 1. The three SD treatments (S1, S2 and S4) varied by time of application while the natural daylength

Table 1.--Greenhouse daylength regimes for bud initiation.

Treatment	Seeding date (1986)	Short day applied (1986)
S1	April 9	July 2
S2	April 9	July 17
S4	April 10	July 29
EG	April 29	n/a
ER	April 9	n/a

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[1]Paper presented at the combined meeting of the Western Forest Nursery Council and Forest Nursery Association of B.C., Vernon, B.C., August 8-11, 1988.

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treatments permitted bud initiation to occur either in the greenhouse (EG) or outside (ER). All seedlings were overwintered outside. On April 30, 1987, seedlings from two FH408 Japanese paperpot® trays were randomly sampled from each of the five treatments and were planted in a randomized block design in a cultivated field at the Midhurst Research Station of the Ontario Tree Improvement and Forest Biomass Institute (44°27'N, 79°44'W). A total of 150 seedlings per treatment were assessed weekly for bud break and shoot elongation. Beginning 39 days after planting and at weekly or biweekly intervals thereafter, a sample of 20 seedlings per treatment was removed randomly from the plantation and shoot tips were examined under a dissecting microscope for signs of bud initiation, evident as newly differentiated budscales at the base of the vegetative apex. Seedling height at planting and new shoot length were measured in the fall, after shoot growth had ceased.

RESULTS AND DISCUSSION

Seedlings that received SD bud initiation regimes in 1986 (treatments S1, S2, S4) began to break bud sooner than did seedlings from ND bud initiation regimes (fig. 1). In general, seedlings from the SD regimes attained maximum percentage bud break 14 days after planting while the seedlings from the ND regimes did not reach that point until 21 days after planting. Heide (1974) found a similar relationship between SD bud initiation regimes and the timing of bud break in Norway spruce (*Picea abies* [L.] Karst.). It is likely that the earlier flushing SD seedlings in this experiment were at greater risk of being damaged by late spring frosts. Although such frost damage was not observed in this 1987 experiment, it has occurred in a similar trial in 1988 where approximately 41% of the terminal shoots in SD seedlings were killed by late spring frosts as compared with 3% mortality in the shoots from ND bud initiation regimes. The extent of damage to SD seedlings could be expected to vary with timing and severity of frost exposure.

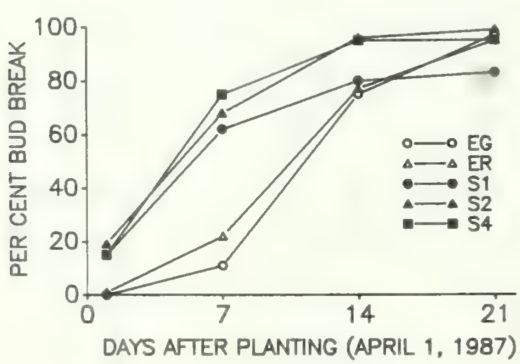

Figure 1.--Bud break in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

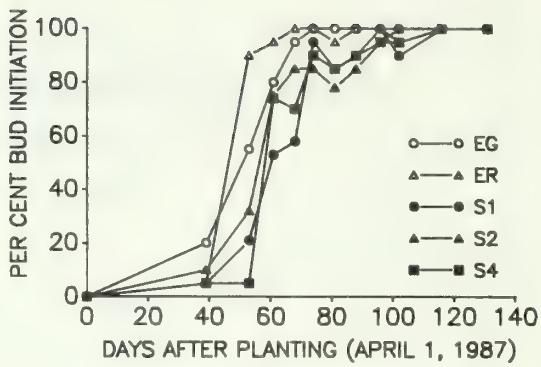

Figure 2.--Bud initiation after planting in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

First signs of bud initiation were detected in all treatments 39 days after planting (fig. 2) but 100% bud initiation was not reached in each of the SD treatments until 3 to 6 weeks later than in the ND treatments (fig. 3). The effect of later bud initiation is apparent in the relative proportion of seedlings still exhibiting active growth throughout the late summer (fig. 4). Active seedlings were those in which weekly terminal shoot elongation exceeded 5 mm. After June 3, there were always more SD seedlings active in the plantation than there were ND seedlings. By August 12, 8% of the SD seedlings were still elongating while less than 1% of the ND seedlings were. Because of the greater proportion of SD seedlings continuing growth, a larger number of SD seedlings would be at risk of being damaged by late summer frosts.

Although seedlings from the SD regimes were shorter when planted, their growth after outplanting at the end of the first growing season was greater than seedlings from the ND regimes

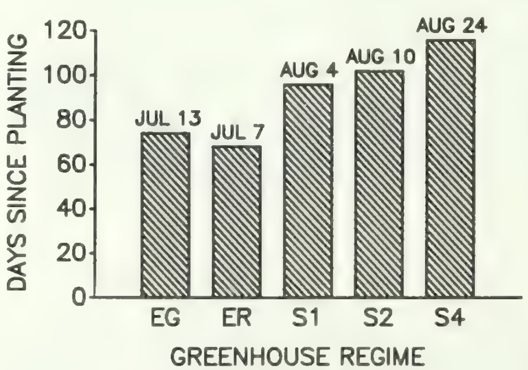

Figure 3.--Date and number of days after planting when 100% bud initiation was attained in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

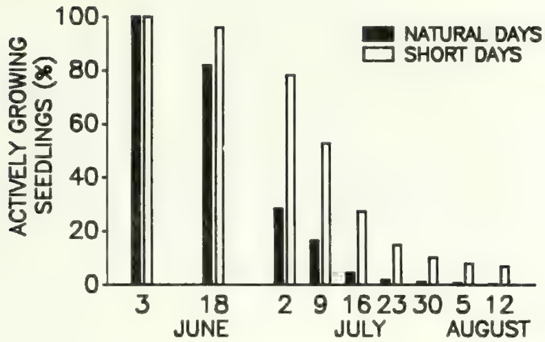

Figure 4.--Percentage of seedlings exhibiting active shoot growth in first season after planting. Natural day values are grand means from EG and ER treatments and short day values are grand means from S1, S2 and S4 treatments.

(fig. 5), primarily as a result of earlier bud break and later bud initiation. Similarly, Heide (1974) found greater growth in Norway spruce seedlings exposed to SD in the previous year for up to 3 years after planting, but did not attempt to correlate this with the timing and duration of shoot growth. In contrast, our results from a plantation estabished in 1986, indicate that after-effects did not persist past the first season in the field.

The mechanism by which a two week short daylength treatment can have such a dramatic effect on the timing and duration of shoot growth in the field more than one year after exposure is still unknown. At the Ontario Tree Improvement and Forest Biomass Institute, studies are

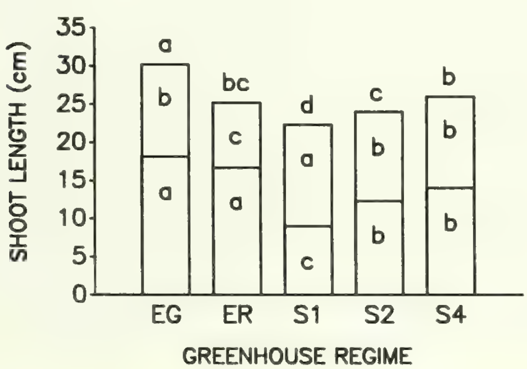

Figure 5.--Shoot measurements for seedlings grown with natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous year. Different letters indicate significant differences ($p<0.05$) between treatment means for seedling heights at planting (lower bars), shoot elongation after planting (upper bars) or total seedling heights (combined bars).

currently in progress to determine some of the consequences of this growth phenomenon. For example, frost hardiness testing in the late summer and autumn is being carried out on outplanted black spruce seedlings from SD and ND regimes to determine whether differences in the timing of frost hardening occur. Intensive monitoring of operationally planted seedlings is underway to assess the risk of damage from frost associated with planting seedlings that flush sooner and set bud later. Needle production in the field is being compared to needle primordia content of the bud prior to planting to determine if free growth accounts for the greater growth found in the SD seedlings. It is yet to be determined whether the nursery production benefits and greater first-year seedling growth potential derived from SD treatment outweigh the risk of frost damage associated with earlier bud break and later budset in black spruce seedlings.

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Recommendations and Alternative Growing Media for Use in Containerized Nursery Production of Conifers: Some Physical and Chemical Properties of Media and Amendments[1]

R.K. Scagel[2] and G.A. Davis[3]

Abstract.-- Physical and chemical properties of various nursery media were examined at the start of the crop cycle of containerized Englemann spruce. Preliminary results showed physical and chemical properties of the peat and amendments are highly variable. Combined, these ingredients produce variable media. The results highlight the need for monitoring the media physical and chemical properties and altering nursery culture to accommodate media properties.

INTRODUCTION

Nursery media contain solids, water, air, and eventually plant roots. The ideal growth medium for nursery culture should: permit healthy root development; be free of pathogens; offer physical stability; and supply water, nutrients, and air. This ideal medium should retain its properties throughout culture and be consistent from one crop to the next (Bunt 1976).

In the real world, peat-based growth media vary in their physical and chemical properties (Haynes and Goh 1978, Prasad 1979). Media also vary in their rate of decomposition (Langerud and Sandvik 1987). Ideal conditions for crop growth are also ideal for media decomposition. Decomposition reduces the aeration porosity of media. Poor media aeration alters root morphology and physiology (McKevlin et al. 1987) and is responsible for decreased seedling vigor and stature (Hocking 1972). Outplanting performance of seedlings grown in poorly aerated media is suspect (Hellum 1981).

Variable peat quality and failure to recognize this variability in crop management has been implicated in the increasing incidence of root diseases in container-grown conifer seedlings. Perlite, wood waste, and rockwool, have been suggested as alternatives to vermiculite in Cornell Peat-Lite mixes (Boodley and Sheldrake 1967) and may provide a means of altering peat properties. Different amendments appear to yield crops with different morphological attributes and plantation survival and growth (Phipps 1974). Amendments alter the porosity and nutritional regimes of nursery culture and, like peat, are variable. Species may respond deferentially to amendments.

STUDY OBJECTIVES

This study examines the physical and chemical properties of various media and amendments. The results report on the initial properties of a variety of media. Future results will report on the degradation of media and cultural consequences for seedling vigor. The preliminary results are presented to permit growers to make comparisons with their media.

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[1] Poster session presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2] Rob Scagel is principal consultant with Pacific Phytometric Consultants, Richmond, B.C.

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MATERIALS AND METHODS

Nurseries were canvassed to determine the range of operational and experimental media being used. Only Englemann spruce crops grown in PSB 313-sized containers were considered. Thirteen media and their amendments were sampled from both coastal and interior nurseries (Table 1) to include a wide range of nursery cultural conditions. Letters reference the media and numbers reference their amendments. Not all the amendments examined were incorporated into the media sampled.

Various physical and chemical properties were examined. Methods of analyses were selected that were used in forest nurseries or related industries. All analyses were carried out in triplicate.

Chemical properties

pH and electrical conductivity (EC) -- pH and EC were measured using a soil:distilled water solution (Day et al. 1979; McKeague 1981). These and other methods are used in the nursery industry.

Ash -- The ash content was determined using the Loss on Ignition method (McKeague 1981). Ash content is expressed on a % oven dry weight.

Table 1.-- Nursery location, media, and amendments used. Media are identified by letters given parenthetically. Amendments are references by numbers.

Nursery	Location	(#)	Media	Amendments Used
1	Coast	(A)	6P:4V:1V	6, 11, 12
2	Interior	(B)	3P:1V	7, 11
	Interior	(C)	3P:1R-	7, 19
	Interior	(D)	1P:1S	7, 14
3	Coast	(E)	3P:2V	9, 11
	Coast	(F)	3P:1S	9, 15
	Coast	(G)	3P:1R+	9, 21
	Coast	(H)	3P:1R-	9, 17
4	Coast	(I)	3P:1V	8, 11
	Coast	(J)	1P:1S	8, 16
5	Interior	(K)	P	10
	Interior	(L)	3P:1R-	10, 17
	Interior	(M)	9P:1R-	10, 17

Media Symbols: P- Peat (1-10);
V- vermiculite (11); Pe - perlite (12);
S- Douglas-fir sawdust (13-16);
R+ - hydrophobic rockwool (17-19);
R- - hydrophilic rockwool (20,21)

Total carbon, nitrogen, sulphur -- Total carbon (TC) and total sulphur (TS) were determined using the Leco Analyzers (McKeague 1981). Total nitrogen (TN) was determined colorimetrically using the Auto Analyzer (Lavkulich 1981). All values are expressed as a % of oven dry weight.

Physical properties

Particle size -- Two methods were used to determine particle size distribution: dry and wet (rubbed fibre) sieve. The dry-sieve analysis is currently used in the British Columbia forest nursery industry to assess peat quality (Gates, pers. comm). The wet-sieve analysis (Day et al. 1979) is the method most often used in the peat industry (Farnham 1968). In both methods four sieve sizes were used: No. 5 (4mm), No. 10 (2mm), No. 20 (0.85mm), and No. 100 (0.15mm). Dry-sieve analyses are expressed as the percentage of air dry mass. Wet-sieve analysis is expressed as a percent of an oven dry mass. The coarse:fine ratio (C:F) is the ratio of weight of particles greater than 2mm ("coarse") to particles less than 2mm ("fine"; Carlson 1979).

Water retention -- Media water contents of 3cm-high, undisturbed container cells contents, were determined at soil water tensions of 0.03, 0.06, 0.10, and 0.33 bars using a Richardson pressure plate apparatus (McKeague 1981). The media water contents are expressed volumetrically (g H_2O/ cm^3) and gravimetrically (g H_2O/ oven dry weight). Expressing results gravimetrically permits relating nursery gravimetric sampling results to lab results.

Watering regime -- During the early growing season each of the participating nurseries determined the gravimetric water contents of the media just before irrigation and 2 hours after irrigation. This sampling includes the extremes of irrigation. These water contents were then compared to the lab-determined gravimetric water retention curve to provide information on the water tensions experienced by the crop.

PRELIMINARY SURVEY RESULTS AND DISCUSSION

Media will be resampled at the end of the crop cycle to determine the degree of media degradation. Gravimetric sampling in the nurseries will be repeated later in the crop cycle. The effect of these media properties on seedling growth, particularly roots, will also be examined. Recommendations cannot be presented without data on the seedlings.

Peats. -- The unamended peats had variable chemical properties (Table 2), particularly total sulphur. All the peats sampled were within the chemical guidelines set out by Carlson (1979). The combination of chemical attributes varies.

Dry-sieve particle size analysis indicated that several peats had many fines (Table 3) and would be regarded as unacceptable by Carlson's (1979) standards. Wet-sieve analysis dispersed many of the aggregates yielding still lower coarse:fine (C:F) ratios. The ranking of the peats changed depending upon the method of sieving used. The C:F ratios may not be adequate to discriminate among peats - similar C:Fs can have very different particle size distributions within each of the broad size classes.

Table 2. Peat chemical properties. Peats have been arranged in order of decreasing pH. pH and EC from an distilled water solution. EC expressed as mS/cm.

Peat	pH	EC	%ASH	%TC	%TN	%TS	C/N
5	4.70	.39	9.8	47.1	1.43	.50	32.9
1	4.49	.32	6.4	41.5	.84	.68	49.4
9	4.40	.30	8.8	43.7	1.09	.72	40.1
3	4.38	.83	6.7	41.5	.87	.44	47.7
8	4.15	.29	7.3	50.8	1.11	.43	45.8
4	4.14	.31	5.2	44.1	1.05	.25	42.0
7	3.99	.14	4.6	46.1	1.06	.14	43.5
6	3.96	.23	7.4	45.9	.94	.12	48.8
2	3.89	.16	6.4	41.8	.81	.11	51.6
10	3.85	.16	5.9	46.4	.75	.10	61.9

Table 3. Peat particle size analysis. Peats have been arranged in decreasing C:F order.

	Mesh Size (% weight retained on sieve)					
Peat	No.5	No.10	No.20	No.100	No.100+	C:F
Dry-Sieve Analysis						
3	38.5	18.0	21.9	20.1	1.5	1.30
2	29.3	20.6	22.1	24.0	4.0	1.00
6	27.5	17.3	20.7	29.3	5.2	.81
10	19.9	20.1	25.1	34.2	.7	.67
8	18.8	14.1	22.2	36.2	8.7	.49
7	14.4	12.6	21.4	41.5	10.1	.37
1	.0	19.3	23.5	44.8	12.4	.24
9	4.2	10.8	24.3	48.7	12.0	.18
4	2.0	10.2	21.3	47.5	19.0	.14
5	3.0	4.6	16.6	58.8	17.0	.08
Wet-Sieve Analysis						
2	14.2	11.8	19.2	29.5	25.3	.35
4	6.2	10.9	18.2	35.9	28.8	.21
1	5.9	10.6	22.5	35.0	26.0	.20
5	5.4	6.8	18.2	44.1	25.5	.14
3	2.8	8.3	20.5	37.2	31.2	.12

Table 4. Peat water retention analysis. Results expressed on a volumetric basis. Peats arranged in order of decreasing aeration porosity (AIR).

	Water tension (bars)							
Peat	0.00	0.03	0.06	0.10	0.33	AIR	BD	PORE
5	86.1	32.3	27.8	24.4	20.2	53.8	.085	93.9
3	96.5	45.5	41.1	34.2	26.4	51.0	.085	94.1
1	82.6	37.4	30.6	27.0	19.6	45.2	.084	94.1
2	80.4	39.4	33.8	30.3	25.1	41.0	.085	94.0
4	71.7	32.0	27.4	23.6	20.0	39.7	.084	94.0

AIR - aeration porosity (% volume)
BD - bulk density (g/cc)
PORE - effective porosity (% volume)

Table 5. Media amendment chemical properties. Amendments have been arrangde in order of decreasing pH. pH and EC from a distilled water solution. EC expressed as mS/ cm. Note: not all amendments examined were included in the media.

#	pH	EC	%ASH	%TC	%TN	%TS	C/N
Hydrophilic rockwool							
20	8.67	.23	99.1	1.20	.01	.59	120
Perlite							
12	7.61	.17					
Hydrophobic rockwool							
17	7.03	.11	99.2	.60	.004	.22	150
18	6.78	.02	99.7	.90	.02	.18	45
19	5.93	.11	97.9	4.50	.21	.01	21
Vermiculite							
11	6.85	.20					
Sawdust							
13	5.68	.07	.70	46.3	.07	.02	661
14	4.36	.22	.11	47.2	.09	.01	524
15	4.03	.44	.40	48.0	.07	.01	686

Other analyses (Table 4) indicated that the peats were very similar in their bulk densities (0.084 to 0.085 g/cc). Over 94% of the volume of the peats is occupied by air (i.e. 6% are solids). Water available between saturation and 0.33 bars ranged from 47 to 60% of the volume of the peat. The aeration porosity of the media did not relate well to the C:F ratio. The largest drop in water retention occurs between saturation and .03 bars. Peat physical properties appeared less variable than the chemical properties. Many of the physical properties (i.e. C:F ratio, air capacity) were outside the guidelines set out by Carlson (1979).

<u>Amendments</u> -- Like the peats, amendments were highly variable in their chemical properties (Table 5). Some of the rockwools had particularly high pH values and total sulphur. Predictably, the Douglas-fir sawdusts had very high carbon:nitrogen ratios and acid pH.

Particle size analysis of the sawdusts (Table 6) indicated that they could be as variable as the peat. One sawdust had a particularly small coarse:fine ratio.

Table 6. Sawdust particle size analysis. Sawdusts arranged in order of decreasing C:F ratio.

#	Mesh Size (% weight retained on sieve) No.5	No.10	No.20	No.100	No.100+	C:F
13	22.6	39.9	31.1	6.0	.4	1.67
14	14.7	40.5	36.0	8.5	.3	1.23
15	2.9	25.0	43.3	27.7	1.1	.39

Table 7. Media chemical properties. Media have been arranged in order of decreasing pH. pH and EC from a distilled water solution. EC expressed as mS/cm.

#	pH	EC	%ASH	%TC	%TN	%TS	C/N
Hydrophilic rockwool-amended media							
G	5.78	2.41	65.7	16.0	.6	.36	26.7
Hydrophobic rockwool-amended media							
M	5.74	.69	29.4	31.4	.8	.13	39.3
L	5.64	.86	55.3	21.9	.5	.16	43.8
H	5.44	3.40	72.2	13.3	1.0	.40	13.3
C	5.18	1.09	27.7	32.9	1.2	.37	27.4
Vermiculite and perlite-amended media							
A	5.27	1.09	40.0	27.6	.9	.35	30.7
Vermiculite amended-media							
E	5.26	2.69	50.2	21.8	1.9	.55	11.5
B	4.82	1.13	24.4	33.4	1.3	.37	25.7
I	4.04	1.84	30.5	31.9	1.1	.44	29.0
Sawdust amended-media							
D	5.15	1.23	7.4	41.2	1	.24	41.2
F	4.44	2.87	5.5	40.4	1.3	.47	31.1
J	3.95	2.27	4.7	41.9	1.2	.37	34.9
Pure peat media							
K	4.45	.80	9.8	38.6	.8	.13	48.3

Table 8. Media wet sieve particle size analysis. Media have been arranged in decreasing C:F order.

#	Mesh Size (weighted retained on sieve) No.5	No.10	No.20	No.100	No.100+	C:F
Sawdust-amended media						
J	11.7	30.6	21.3	24.2	12.2	.73
D	14.3	25.7	24.4	22.4	13.2	.67
F	3.6	21.1	27.6	28.2	19.5	.33
Vermiculite and perlite-amended media						
A	7.4	23.8	22.8	28.4	17.6	.45
Hydrophobic rockwool-amended media						
H	2.5	30.3	20.7	26.9	19.6	.49
M	9.8	15.9	20.8	31.7	21.8	.35
L	5.7	17.5	19.1	32.5	25.2	.30
C	11.7	10.6	21.2	35.1	21.4	.29
Pure peat media						
K	13.0	13.1	22.1	33.7	18.1	.35
Vermiculite-amended media						
I	7.3	19.3	24.7	33.1	15.6	.36
E	2.2	22.7	18.9	34.1	22.1	.33
B	5.9	16.7	21.7	37.7	18.0	.29
Hydrophilic rockwool-amended media						
G	1.6	19.0	18.1	34.4	26.9	.26

<u>Media</u>. -- Predictably, variable ingredients yield variable media. In many instances the physical and chemical effects of amendments on the media are confounded by peat and nursery differences. This confusion limits the ability to make critical comparisons among the media but allows an appreciation of the range of cultural conditions under which the same crop is being grown.

The chemical properties (Table 7) display a wide range of values. The EC values are particularly high reflecting the presence of slow-release fertilizers or recent irrigation with nutrient solution. The rockwool amended media had the highest pH. Media pH were ranked similar to ranking of the amendments.

On a wet-sieve basis, media particle size analysis displayed less variability than the unamended peats (Table 8). The C:F ratios from wet sieve analysis are consistently less than the dry sieve analysis. The sawdust-amended media had the largest coarse:fine ratios, with the medium prepared with the finer sawdust having a much smaller C:F ratio.

Water retention results (Table 9) indicate substantial differences in saturation water content. Values given for rockwool-amended media were difficult to obtain because the media did not wet readily. Bulk densities vary more than unamended peats as do the effective porosities. These differences reflect a nursery-effect in mixing and loading media.

On average the sawdust amended media have the largest aeration porosities. The vermiculite amended media had the lowest aeration porosities. There did not appear to be a relation between the C:F ratio of the media and the aeration porosity.

Watering regimes. -- It was assumed that media were maintained at low soil water tensions throughout the growing season. However, gravimetric sampling indicated a range of watering regimes. Some nurseries were irrigating media at soil water tensions less than 0.06 bars, others at tensions greater than 0.33 bars - outside the range for which water retention curves were developed.

Table 9.--Media water retention analysis. Results expressed on a volumetric basis. Media arrange in decreasing aeration porosity (AIR).

	Water tension (bars)							
#	0.00	0.03	0.06	0.10	0.33	AIR	BD	PORE
Sawdust-amended media								
F	84.6	45.9	38.0	31.7	25.4	38.7	.131	91.2
J	80.4	53.6	44.2	36.5	29.8	26.8	.121	91.1
D	78.6	57.6	45.6	36.8	29.5	21.0	.136	90.9
Hydrophobic rockwool-amended media								
C	81.9	49.0	39.3	32.6	27.8	32.9	.120	92.9
L	75.3	48.6	39.1	32.6	27.3	26.7	.183	90.5
M	82.3	55.7	46.2	39.3	32.6	26.6	.135	91.3
H	48.7	27.2	22.6	19.2	17.3	21.5	.202	90.8
Hydrophilic rockwool-amended media								
G	66.3	40.2	31.6	26.3	22.2	26.1	.223	89.6
Pure peat media								
K	85.7	61.6	53.3	44.5	35.9	24.1	.117	91.5
Vermiculite-amended media								
E	78.7	52.3	45.6	40.8	34.4	26.4	.126	93.3
B	79.1	56.0	46.8	39.7	32.3	23.1	.117	92.8
I	75.4	54.0	42.9	35.7	29.7	21.4	.111	92.7
Vermiculite and perlite-amended media								
A	75.9	57.7	48.5	40.0	30.1	18.2	.131	92.4

AIR - aeration porosity (% volume)
BD - bulk density (g/cc)
PORE - effective porosity (% volume)

SUMMARY

The physical and chemical properties of peat and amendments are highly variable. Combined, these ingredients produce a wide range of media. The variability of media must be recognized in cultural management.

There is are advantages and a freedom in mixing one's own growth media. Along with this freedom comes the responsibility to recognize and alter the crop culture to accommodate the properties of the media.

Alternative nursery media must be examined for physical and chemical properties. If mis-managed, even the ideal medium may not be capable of yielding a healthy, acceptable crop.

ACKNOWLEDGMENTS

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The "Izing" of British Columbia Nurseries[1]

I.D.M. Armit[2]

INTRODUCTION

It has been 12 years since the Western Forest Nursery Council held the 1976 Conference in British Columbia, at Surrey. It is a little over two years since I approached the Ministry of Forests Executive with the proposal that we co-host the 1988 meeting in Vernon, B.C., and requested authorization for Ralph Huber to travel to the United States to extend the invitation to our sister associations, so that all the planning, preparation and organization that is essential for a successful conference could commence.

Since I expected to retire in early 1990, I had anticipated that the 1988 Conference would be the last I would be attending as Manager of Provincial Nurseries. I was looking forward to this meeting as the cap-stone event in my career as Nursery Manager, providing me with the opportunity and the forum to wax eloquent about all the marvelous improvements we achieved during those 12 years, in nursery techniques, in quality of stock produced, in economic efficiencies, etc., etc.

I did not anticipate that the mad rush of events and changes during the first 10 years would actually accelerate in the next two years. The winds of change in fundamental forest management policy in British Columbia have not only dramatically altered the landscape of forest nursery practices and responsibilities for reforestation, but left the writer on side-lines, prematurely retired, no more than an interested spectator to the latest developments in "Fantastic Land".

CONTAINERIZATION

In 1970, seedling production was approximately 55 million seedlings, all basically field grown bareroot seedlings, with a few transplants and a test program of containerized seedlings. By the time of the 1976 Conference in Surrey, the Province of British Columbia was growing 80 million seedlings annually, all in nine Ministry of Forests Nurseries, 20 million container-type seedlings and 60 million bareroot seedlings, including 8 million transplants. The program of seedling production in provincial ministry nurseries peaked in 1980, at 105 million seedlings, consisting of 75 million bareroot seedlings and 35 million container-type seedlings. Since then, the Ministry nursery program has remained about 100 million seedlings annually but the ratio of container-type seedlings to bareroot seedlings has been reversed to 70 percent containers and 30 percent bareroot. Since 1980, all program increases have been achieved in private sector nurseries, which in 1988 had risen to more than 135 million trees. Except for 7-8 million bareroot seedlings being grown in one licensee nursery, all are container-type seedlings. Consequently, the total provincial program annually is now about 237 million trees, of which 200 million are container-type stocks.

Further, a rapid increase in large bareroot transplant stock which reached over 30 million by 1984, with a market demand for over 50 million, has been replaced by large two-year container stock types, particularly for hot lift and summer outplanting. As a consequence, the production of bareroot transplant stock types has dropped back to around 5-6 million annually and should drop even lower in the next two years.

COMMERCIALIZATION

Until 1980, all seedling production for reforestation on Crown Land was produced in Ministry nurseries. In 1976, the Pearse Royal Commission report on forestry issues in B.C. was tabled. Among its many recommendations and conclusions was the finding that there did not seem to be any good reason to continue the policy of excluding private nurseries from the opportunity to produce seedlings for Crown Land reforestation. Subsequent to the Royal Commission report, a task group chaired by the writer was formed with a mandate to investigate and prepare a white paper on the potential for

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[1] Paper presented at the combined meeting of the Western Forest Nursery Council and the Forest Nursery Association of British Columbia, Vernon, B.C., August 8-11, 1988.

[2] I.D.M. Armit, retired, former Manager of Nurseries, Silviculture Branch, Ministry of Forests, Victoria, B.C.

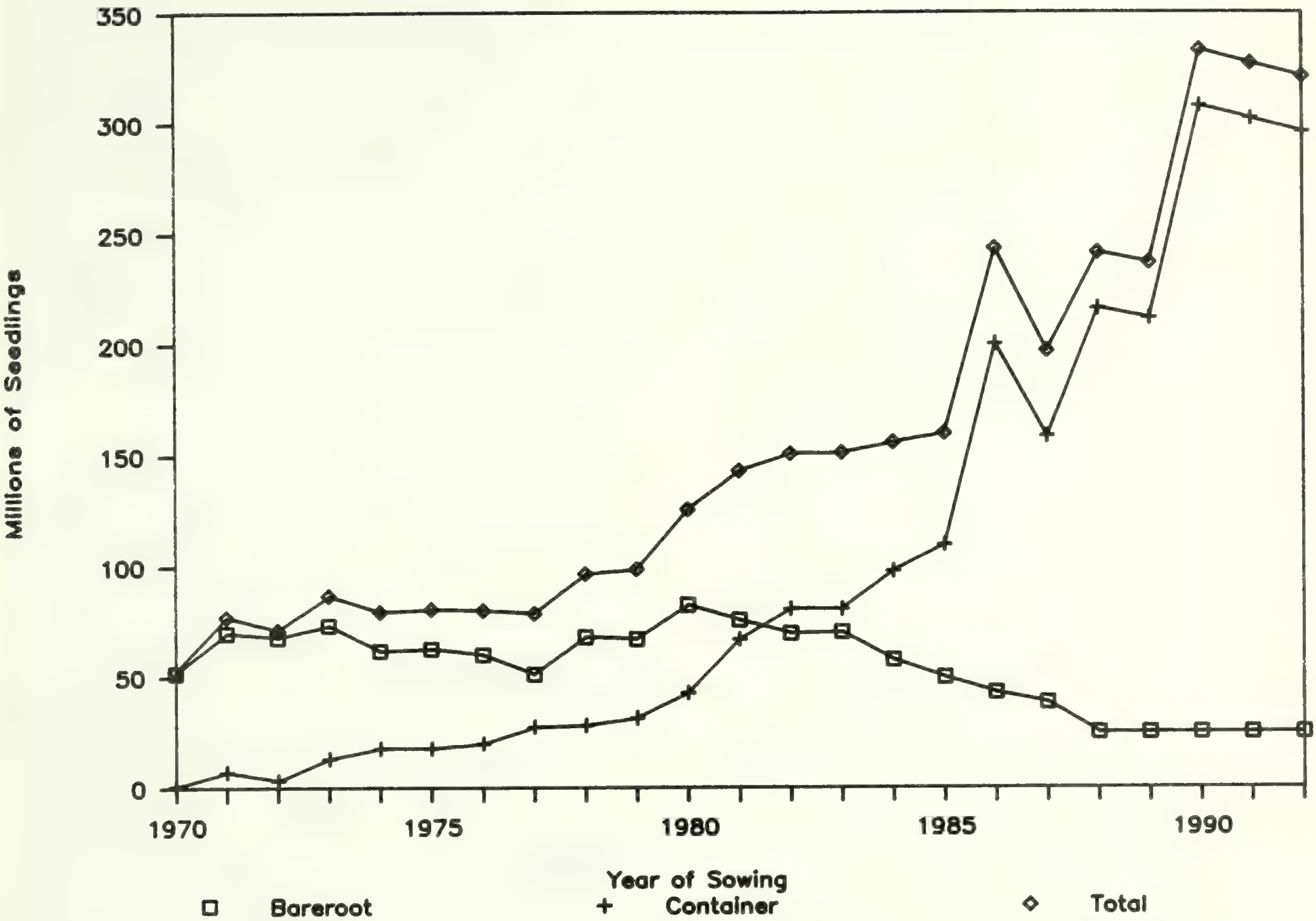

Figure 1.--Nursery production, bareroot and container, showing millions of seedlings sown for from 1970 and anticipated production to 1992.

private sector participation in such tree seedling production.

Among the more significant conclusions reached by the task group, subsequently endorsed by both the Ministry of Forests Executive and by the government, were (1) that the five and ten year targets for expanding seedling production in the 1980's could only be achieved by private sector participation, due to the staffing and capital cost constraints on government facilities; (2) that the Ministry of Forests nursery production should be capped at around 100 million seedlings annually, with future emphasis to be placed on conversion from bareroot to container stock types, to satisfy existing demands; (3) that all future increases in seedling production for Crown Land reforestation requirements should be directed to private sector nurseries through appropriate contractual arrangements.

From this policy, the Forest Nursery Association of British Columbia was eventually born. Private nursery production started in 1980 with 8.8 million seedlings being sown for, rising to more than 135 million seedlings in 1988, produced in six licensee and over 25 commercial nurseries. The reforestation program which will approach 240 million trees in total in 1989, is expected to peak under present management criteria at about 325 million in 1991-92. By this time, all but 30 million trees will be produced in private nurseries, and all but possibly 20-25 million, are expected to be container stock types.

COMPUTERIZING

Almost hand in hand with the phenomenon of containerization and commercialization was the development of computerization.

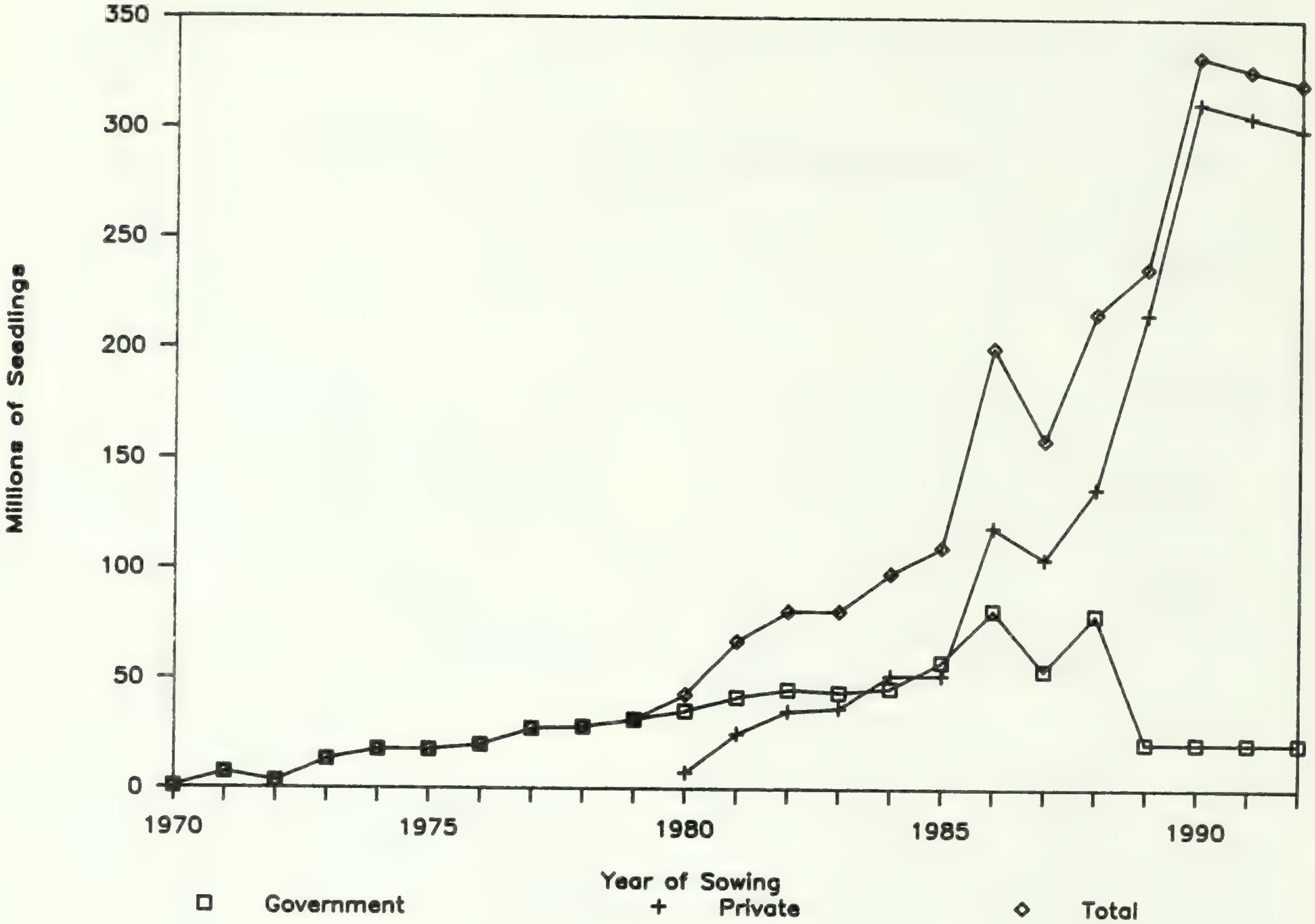

Figure 2.--Container production showing millions of seedlings sown for from 1970 and anticipated production to 1992.

Computers were introduced into operational nursery management activity in 1979, basically to rapidly process thousands of sowing requests into numerous nurseries, consistent with their growing capacities, contractual obligations and stock type capabilities.

Prior to the introduction of computers for this purpose, sowing request allocation procedures required manual processing that took 2-3 months to complete. It was the principal bottleneck to prompt withdrawal and preparation of seed for early spring sowing. As we gained experience, modified our management time-lines and made our computer programs more sensitive to our needs, the lead time from receipt of sowing request to sowing allocation was reduced from months to weeks to days, and finally, same-day turnaround of individual request data by nursery is now achievable.

Computers were initially introduced as an operational management tool to "crunch numbers". As they became more versatile, more sophisticated, and less expensive, they became tools for quality control technicians and biologists to track seedling performance and monitor the interactive processes of environment and seedling development; they enable the operational technician to modify that biological environment to optimize development in accord with the biologists' recommendations. Fully automated environmental control systems with computer managed biofeedback are operational realities.

More recently, with network hardlines and integration of programs, the same computer systems are giving higher management and executives a direct window and immediate access to all on-site operational information, to the same information and timeline used by the on-site technicians. There are no secrets anymore.

Data can no longer be winnowed, interpreted, held in reserve or screened through several levels of management over extended periods of weeks or months. Management can make its own decision as to what is relevant or extraneous, on a real time basis. Middle level management becomes increasingly superfluous to the decision-making process - fewer people on fewer levels are needed to keep the process functionally viable; management level "downsizing" becomes another feasible option. Computers are excellent tools for operational activities in nurseries; they are also excellent tools for strategic management decisions; they may prove to be the nemesis for most mid-management people.

DOWNSIZING

In every year since 1981, there has been a decrease in the manpower resources allocated to Ministry nursery operations. Some years the decrease has been small, 3-5 percent; some years it has been large - over 20 percent, but every year fewer resources.

Innovative techniques had to be implemented to offset this reduction, including contracting out of work, use of piece work incentives, reduction or elimination of ancillary services, and transfer of responsibilities to the private sector. In 1988 we have the ultimate form of downsizing. The conversion of all but two of the eleven Ministry nurseries to private ownership, with the closure of any facility which does not prove to be an economical viable entity in the private market place. A further 177 man years of nursery labour and technical staff, headquarters administration, and specialized extension services will be eliminated, over 60 percent of current Ministry nursery services staff levels, a significant downsizing to anyone's standard.

PRIVATIZING

It is not my intent to explore the issue of competition between or the relative efficiency of government versus private nurseries. Thomas Landis presented an excellent paper on that subject at the Intermountain Nursery Association meeting in Oklahoma last year. All of his definitions and most of his commentary are relevant to the experience in British Columbia.

The single major distinction is that, in B.C., the Crown owns 95 percent of the forest land base. Until September 1987, our policy was that the landowner (i.e., the Crown) was ultimately responsible for the cost of reforestation, regardless of who managed or harvested the trees under license.

Under that philosophy, the Crown supplied planting stock for all reforestation on its lands at no cost to the licensee. From 1928 to 1979, such stock was only produced in nurseries operated by the Crown. From 1980 to 1987, as I previously indicated, private nurseries were encouraged to participate in seedling production for Crown land reforestation under appropriate contractual agreements; the Crown continued to supply such stock at no cost to the licensee until this year.

A major policy change - one could almost say revolutionary change, since it discarded a policy that had stood for 60 years - occurred in September 1987. The government, with supporting legislation, made the licensees solely responsible for all costs of silviculture, including costs of reforestation and planting stock on all areas harvested by forest licensees after October 1, 1987. This policy change effectively shifted the burden from the Crown to the licensees. It also freed the licensees to spend their money as they saw fit to achieve the silviculture objectives set out in their approved pre-harvest silviculture prescriptions. In reforestation work, this meant they could grow their trees in their own nursery, buy them, or contract to have them grown in a commercial nursery of their own choosing. They could also purchase or order them from a Ministry facility; however, this last option was discouraged except where bareroot seedlings or speciality container-transplant stocks were required, since the Ministry was initiating the parallel process of privatizing Ministry nurseries.

The major shift in policy meant that total Ministry capacity would, within five years, exceed the Ministry's internal need for seedlings to reforest on forest lands which were not licensee responsibility (such as wild fire and small business program harvest areas still managed by the Crown). The incentive was thereby created to either privatize or close most of the Ministry nursery capacity, preferably while economically viable units could be incorporated into the expending private sector market for tree seedlings.

Consequently, one nursery has already been sold, six more are scheduled to be transferred to private ownership within the next month or so to a consortium led by Charlie Johnson, past Director of our Silviculture Branch. Two more nurseries will likely be on the market in early 1989, or will be designated for alternate land use. Only two nurseries, Surrey and Skimikin, will remain to provide some of the Ministry's internal requirements for reforestation on Crown owned and managed forest lands, and to permit continued experimentation with new nursery techniques, improvements in technology and automation.

The Government of British Columbia provided generous early retirement packages which not only facilitated the process of staff downsizing but removed, by volunteer decision, most of the middle and senior management people who might have most resisted the proposed changes in policy. The Government facilitated the process

of employee participation in the purchase of privatized facilities by freely providing financial and business planning services to develop the required proposals.

The Government passed Draconian legislation that forced the transfer of responsibility for reforestation to the forestry industry, but it then eased the impact by providing a 5 year phasing-over period for implementation. By judicious use of such measures as honey to sweeten the medicine, the Government of British Columbia achieved its triple objective of privatization, downsizing and transfer of responsibilities to the private sector with a minimum of disruption, employee dissension or public resistance to the radical changes in government policies.

The triple-edged sword of privatization, early retirement incentive plans, and radical changes in Forest Service policy on silviculture has changed the world within which Ministry nurseries function and the role which they will be expected to play in future, whether operated as public or private businesses.

MECHANIZING AND AUTOMIZING

From the mid 1960's when seedling production first was increased in a major way through to the present time, a critical emphasis has been to keep costs and manpower requirements in check, by increased mechanization, automation, and employee productivity.

In bareroot sowing, we went from manual broadcast sowing to random drill sowing to species-specific precision sowing standards with specialized seeders. We went from manual lift to Grayco lifters to Fobro lifters to integrated lifter-combines with large bin trailer processing, in association with cold-storage-sorting area complexes. We solved the problems of lateral pruning with species-specific procedures; and were working to operational solve the problem of cross-bed pruning in bareroot seed beds. However, even faster than we improved our techniques for bareroot seedling production, we were converting to container-seedling production. The opportunities for cost and labour savings by automation and mechanization were even greater. Productivity per employee was much higher and improvements were easier to achieve.

We have already begun development of a prototype automatic extraction machine for container-type seedlings. I confidently expect we will see a fully automated container processing line in operational use within three years, capable of extraction, grading, counting, bundling, wrapping and packaging into cartons as a single integrated operation, with only one or two people required to process 10 million seedlings.

THE NEXT DECADE

What are my other predictions for the next 10-12 years? Based on the past 12 years experience, my first prediction is that almost all the other predictions I make will be wrong.

I believe we may have too many eggs in one basket with the current overwhelming reliance on container-stock types. The potential for biological and environmental disaster is extreme in a system that lacks buffer or resilience to adverse influences. A return to significant production of large bareroot or container-transplant stock types seems a reasonable possibility, particularly on sites where prompt establishment of "free growing" plantations is essential for planned rotational growth.

The monopolistic nature of material supplies in container production should be of real concern to all seedling producers - investigation of alternative suitable growing mediums and cost-competitive container structures should be given high priority.

I believe we will also see a major increase in use of local nursery seedling production for hot lift planting in all seasons, avoiding the need for cold storage or long-distance transport logistical planning. The emergence of large 3 to 4 year old planting stock for crop-tree establishment may prove to be a viable economic option in concert with local nursery utilization, along with pre-conditioning of stock prior to shipment to the planting site.

I am sure that forest management firms, freed from the "dead hand" of government, are going to come up with innovative concepts in silviculture and reforestation, perhaps even invalidating the current high reliance on reforestation with nursery grown planting stock, to achieve the objective of "free growing" plantations for which they are responsible to achieve in their approved silviculture plans.

I believe the next decade will see the further development and strengthening of a healthy viable private nursery industry with competent management and technical staff producing superior quality planting stock to meet the site-specific requirements demanded by the forest industry. I believe there will also be a winnowing out of some "weak" nursery operations due to the pressures of competition or the unplanned risks of environmental disasters with which private enterprises unhappily must contend. I believe there will be development of horizontally integrated companies providing all silvicultural services from cone collection, seed processing, seedling production, planting to plantation maintenance, in the same manner that contract loggers provide "stump to dump" services for the large forest companies.

For those who can stay the course, there will be rewards, both financially and in

personal satisfactions. This is a great business to be in, even when the greenhouse gets too damned hot.

In conclusion, there may be meaning to that strange topic phrase "the Izing of Privatization", if the word is spelled I-c-i-n-g. The newest consortium of entrepreneurs operating privatized government nurseries reputedly have outstanding managerial, technical and operational capabilities.

If they are as efficient, technically competent, and informed on all biological issues of seedling production and quality control as they have indicated to the present commercial nurserymen, then the "icing of privatization" will be the incredibly profitable nursery operations they will establish, and the wealth they will individually and collectively accumulate in the years to come by being successful entrepreneurs, to the betterment of all of us residing in British Columbia, depending on the forest resources for our livelihood.

Managing Nursery Information in the 1980's[1]

Michael Pelchat[2]

Faced with a rapidly expanding reforestation program and an outdated manual record keeping system, the British Columbia Ministry of Forests developed a Nursery Information System to manage information on seedling production and distribution. A brief description of the system is presented.

INTRODUCTION

Seedling production in British Columbia went through a period of rapid expansion during the last two decades. The number of seedlings planted in B.C. rose from 26 million in 1969, to 63 million in 1979, and to almost 200 million seedlings in 1987 as shown in Figure 1. This rapid expansion of the reforestation program prompted the Ministry of Forests to review the process of nursery information management in the fall of 1982. The aim was to develop an information system which would cope with the expanding seedling production program, and provide dependable reporting capabilities.

Figure 1. Number of Trees Planted in B.C.

[1] Paper presented at the Western Forest Nursery Association Meeting, Vernon, B.C. August 8-11, 1988.

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The Problem

The record-keeping system in use in 1982 was a manual file card system which provided a few simple summary and detailed reports. This manual system had two major deficiencies. The first was an inability to reconcile the number of seedlings shipped for planting and the number of seedlings actually recorded as planted. In 1981 this difference in seedling numbers produced a "paper loss" gap approaching 10 per cent, and this was expected to get worse as the planting program expanded. The second was the limited number of reports that were manually compiled from the file cards. Any additional reports demanded by forest managers required a large amount of time and effort to produce. Recent advances in information management had raised the information expectations of both the nursery managers and the field foresters, and they were anxious to see this technology applied to seedling information. Thus, it was obvious that the manual system would not cope with the information needs of a rapidly expanding seedling production program, and that some form of computerized information management system was needed to maintain control.

The Ministry of Forests had already utilized computers to assist with the management of the reforestation program. The ordering of seedlings was being handled by a Sowing Request System which assisted in matching the orders from field foresters for seedlings, called sowing requests, with the various government and privately owned nurseries and ensured that forest tree seed and nursery materials arrived at the assigned nurseries at the proper time. A Planting Report System was also under development to capture and report on information related to the annual planting program. The next step was to develop a system to bridge the gap between these two activities and provide the field foresters with information on their seedlings while the stock was being grown in the nurseries and subsequently transported to the planting sites.

The Solution

In the fall of 1982 approval was given to investigate the feasibility of producing a system to manage nursery information. Over the next two years, the existing manual system was evaluated and a proposed Nursery Information System was described. The development of the new system was initiated in the fall of 1984.

The Nursery Information System was to provide an integrated information system to the various agencies involved in reforestation while reducing the overall manual paperflow process of compiling, transcribing, and reporting nursery information. The main objective was to be able to track a sowing request from inception, through the growing cycle in the nursery, to the dispatch of seedlings to the field forester at the planting location. Development of the system was done in phases, with each phase tested in at least two different nursery sites prior to implementation on a province wide basis. The first phase, dealing with inventories and seedling quality, was operational in the spring of 1986, while the seedling storage and distribution phase of the system was operational in the summer of 1987.

The System

The Nursery Information System is a data management system composed of a central system located on a mini-computer at the Headquarters office, and local systems located on personal computers at each automated nursery site and each Nursery Zone Administrative Office as shown in Figure 2.

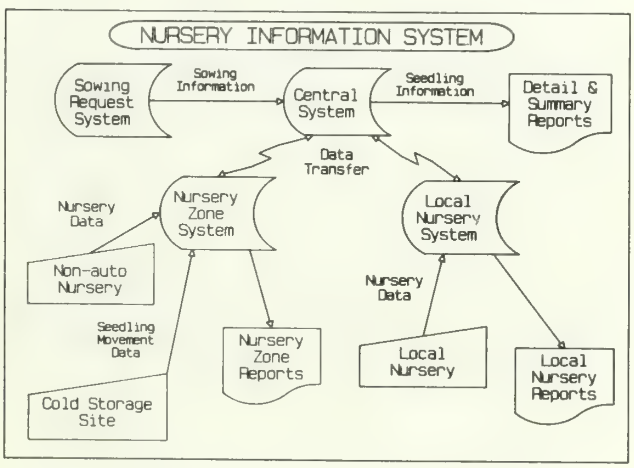

Figure 2. Nursery Information System

The main function of the central system is to receive data from the local sites in the province and update a central database which is then used to produce detailed and summary reports for distribution to the various agencies involved in reforestation, and to the B.C. Forest Service managers and executive officers. A central database is required to handle the complex relationship between nurseries and their clients. At any time a client may have seedlings being grown at several nurseries to take advantage of each grower's expertise with a particular species or stock type. As well, each nursery may be producing seedlings for more than one client. The only way to provide the clients with a report containing all their seedlings is to gather all the data together at one time.

There are three subsystems which make up the local Nursery Information System. These are the Nursery Growing Subsystem, the Quality Control Subsystem, and the Storage and Distribution Subsystem.

The Nursery Growing Subsystem, represented in Figure 3, manages the bulk of the seedling information. The main purpose of this subsystem is to process and report on information pertaining to growth progress, seedling quality, inventory estimation, cultural treatments, and transplant and lift scheduling for all seedling stock from the sowing phase to shipping of these seedlings. The subsystem operates as an online system with local reporting and screen display functions at the nursery sites. Data processing is done throughout the day, and data transfer to the central computer is accomplished electronically over phone lines during the night. A reduced version of this subsystem is also available at the Nursery Zone Administrative Offices to record inventory estimations and pesticide information from nurseries with no local online processor.

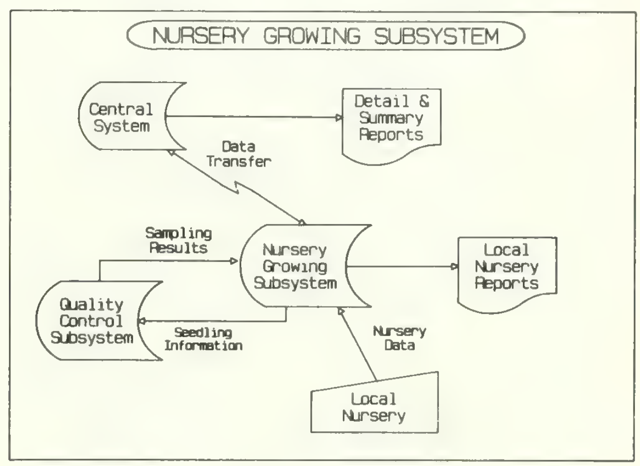

Figure 3. Nursery Growing Subsystem

The Quality Control Subsystem, represented in Figure 4, which assists the nursery technicians with data analysis of seedling information. This subsystem is only available at the nursery sites with local processing capabilities. To estimate inventories and determine seedling quality throughout the growing period, seedling growth status and trends are sampled, measured, statistically analyzed, and reported. The separation of

quality control data from the nursery growing data allows the technicians to sample and analyze seedling data repeatedly and use only those results which they are satisfied with to update the Nursery Growing Subsystem information. This computer aided analysis provides the nurseries and their clients with the ability to modify culling standards and evaluate the impact on the estimates of inventory in order to attain planting priorities. Based on these estimates the field foresters can plan their planting program and define specific shipments for specific sowing requests. This subsystem also records the cultural treatments applied to the crops while the crops are at the nurseries.

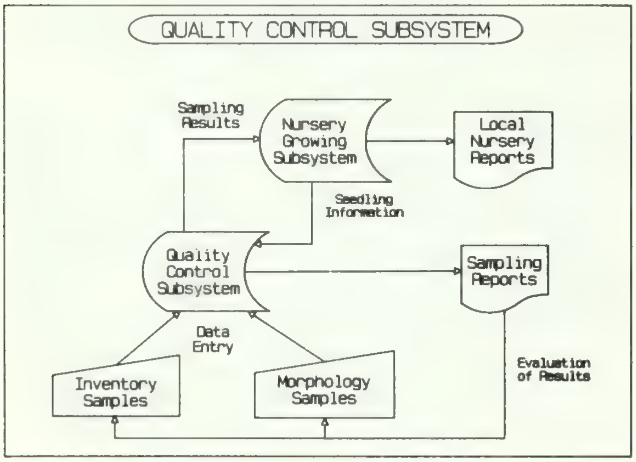

Figure 4. Quality Control Subsystem

The Storage and Distribution Subsystem, represented in Figure 5, is used to coordinate the storage and distribution of seedlings prior to and during the planting season. This subsystem provides the online nursery sites with seedling storage and shipping management functions. Once seedlings are shipped from the nurseries, the management responsibility transfers to the Nursery Zone Administrative Office where a local online version of this subsystem is used to manage seedling movement and storage within the nursery zone.

Shipping can be initiated by a pre-arranged schedule submitted prior to lifting, or via telephone instructions from the field foresters during the planting season. A multicopy Shipping Order/Invoice is utilized to monitor seedling movement from the nurseries to the planting sites. The information on the stock being issued is recorded by the shipper and a copy of the invoice is sent to the local Nursery Administrative Office where the data is entered into the system. The remaining copies are sent with the seedling shipment. At the destination the field forester confirms the amount of stock received and another copy of the invoice with the receipt information is sent to the local Nursery Administrative Office for data entry. This process of matching stock issues and receipts provides stock movement and storage monitoring, regardless of how many times the seedlings are moved, as well as the ability to reconcile stock shipped by the nurseries with stock received by the designated final receiver.

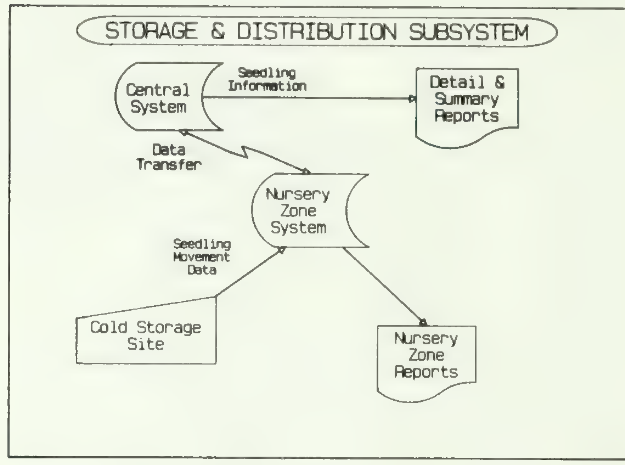

Figure 5. Storage & Distribution Subsystem

Retrospect

The development of an information system to manage the production of over 200 million seedlings was a major undertaking, requiring close cooperation between the users of the system and the programming staff over the five years that the system was developed and implemented. Even with this close cooperation, a large portion of the time and effort was devoted to maintaining and enhancing the system in response to feedback from the users, and changes to government legislation and forest policy. Overall, the system has met the stated objectives and the users have been satisfied with the results. Everyone involved has agreed that the previous manual system would not have been able to cope with the expansion of the seedling production program.

Providing an accurate information system while maintaining the flexibility needed to manage a biological product was a formidable challenge. Of the many lessons learned from the development of this system three stand out as critical to the success of the system:

1. Involve the users from the very beginning.
2. Accurately describe the requirements of the new system.
3. Start small, having a solid foundation of basic functions will provide the necessary support for the additional functions which will be required as the system matures.

Agencies and individuals desiring further information on this system are invited to contact the author.

Cumulative Trauma Disorders in Forest Nursery Workers[1]

Ulrika Wallersteiner[2]

Abstract - This study focused on the upper limb injuries suffered by up to 31% of seasonal nursery workers in British Columbia nurseries. Problems occured primarily in right hand flexors and both shoulders; subjects with no first aid problems were slightly older, had more work experience, and used the neutral hand position more frequently when working.Recommendations include training, rest breaks, maintenance of constant workplace temperature, and the purchase of sit-stand stools.

INTRODUCTION

Logging is one of the major industries in Canada. In order to ensure logging in the future, Canada has an intensive reforestation program, though many feel it is not sufficient. Part of the problem is associated with the occupational health problems experienced by many sorters.

In British Columbia, government nurseries plant and harvest more than 110 million seedlings per year. This represents approximately 50% of the total seedlings raised for reforestation. These nurseries employ approximately 800 workers at the peak of the sorting season. In 1985, 33 Workers Compensation claims involving upper limb injuries to sorters were filed, resulting in 689 lost work days, direct costs of $28,000, and estimated indirect costs of $112,000.

The workers' jobs in the nurseries are very manual intensive, requiring no tools other than the worker's two hands. In the early months of each year, seedlings are lifted from the ground and stored in cold rooms to inhibit their growth. Boxes of chilled seedlings are distributed daily to sorters in a sorting shed, who sit on a stool or stand at a flat work surface. Sorters wearing rubber gloves for protection from chemicals separate the seedlings, using the index or middle finger from the dominant hand to pull while holding the entangled bundle in the other hand. The separated seedlings are sorted or graded into groups suitable for reforestation planting or for discard. Sorters sort approximately 6000-7000 seedlings per day. Bundles of sorted seedlings are placed on a conveyor belt and are transported to a wrapper who packages them in cellophane and chops off trailing roots.

The management of the occupational health problems of nursery workers is made difficult by several factors:

1) The time period for lifting and sorting the seedlings changes from year to year and cannot be determined more than a week or two in advance.

2) Sorting crews consist of both experienced and inexperienced workers.

3) Most ergonomic studies relating to upper limb disorders focus on redesign of hand tools, which are not used in this situation.

METHODS

To assess the extent of the occupational health problems experienced by nursery workers, a questionnaire was developed and distributed at the end of the sorting season to three nurseries and also to head office staff (for control). Approximately 500 subjects were surveyed. Workplace factors were assessed through the questionnaire and by measuring the dimensions of the workstations.

First aid reports gathered during the sorting season were assessed to identify the most common areas of injury and the types of injuries experienced. In addition, all upper limb musculo-skeletal injuries were more accurately defined by having the person affected shade in areas on a body diagram.

Because of the numerous hand manipulations performed during a shift, certain hand motions are believed to contribute to the health problem. Ten tree sorters (five healthy and five infirm) were viedotaped. Eighty hand motions per subject were analyzed in 0.5 second intervals. The shoulder, elbow and wrist joints were reported in either a neutral, flexed, or extended position. Hand deviation was reported either as ulnar, radial, or neutral.

RESULTS

Of the 500 questionnaires distributed, 447 nursery questionnaires and 17 office questionnaires were returned. All subjects reporting arthritis or fractures in the upper limb body parts were removed from the study group, thus eliminating 100 subjects. Responses were then analyzed according to work location, job category, and reporting or

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1. Paper presented at the Western Forest Nursery Association Meeting (Vernon, British Columbia, August 8-11, 1988) .

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non-reporting of hand problems. The resulting subject group totalled 275, with 118 reporting hand problems and 157 having no hand problems. By analyzing certain questionnaire responses using this breakdown, and using the non-parametric z-test, an attempt was made to determine why certain workers experience problems and some do not.

Table I shows that healthy subjects were slightly older and had more work experience as sorters and wrappers, while Table II indicates that infirm subjects consistently experienced significantly ($p<0.05$) more right, bilateral, and frequent hand and shoulder problems.

Table I. -- Characteristics of Healthy and Infirm Subjects.

	Infirm		Healthy	
	Mean	SD	Mean	SD
Years Worked	4.9	3.6	5.2	4.7
Weeks Worked	11.4	7.6	12.2	9.7
Age	35.8	10.1	37.4	11.8
Height	65.0	2.5	64.7	3.1

SD=standard deviation

Table II. -- Distribution of Hand and Shoulder Complaints

	Infirm	Healthy
Hand Discomfort		
Right	43 (36)	
Left	14 (12)	
Both	60 (51)	
Shoulder Discomfort		
Right*	21 (18)	14 (9)
Left	5 (4)	3 (2)
Both*	40 (34)	28 (18)

* = significant ($p<0.05$)
Numbers in brackets represent percentages.

Infirm subjects experienced tiredness, stiff shoulders, headaches, and lower back pain more frequently than healthy subjects, but only the occurence of stiff shoulders was significantly higher. Infirm subjects experienced significantly more pain at the beginning of the sorting season, though both groups experienced more discomfort at the beginning of the season than at the end. Prior work did not seem to affect the distribution or the onset of problems.

The subject groups did not differ with respect to sorting and holding hand preferences. About 60% of workers used the right hand for sorting, while only 13% used the left hand and 12% change hands. Both groups had comparable hand preference distributions; the majority were right handed and 8% were ambidextrous. However, infirm subjects did experience significantly more problems in their hands while wrapping. And, although both groups wear glove liners, a significantly larger proportion of infirm subjects experienced cold hands and muscle fatigue. Table III details workstation problems.

Table III. -- Workstation Problems

	Infirm	Healthy
Lighting		
Too High	9 (8)	10 (6)
Too Low	14 (12)	29 (18)
Working Posture		
Sitting	13 (11)	18 (11)
Standing	58 (49)	72 (46)
Both	46 (39)	65 (41)
Table Height		
Too High	4 (3)	9 (6)
Too Low	36 (31)	32 (20)
Worksurface		
Too Large	0	1 (1)
Too Small	38 (32)	55 (35)

Video analysis showed that workers experiencing health problems tended to deviate more frequently from the anatomically neutral position of the upper joints.

DISCUSSION AND RECOMMENDATIONS

Nursery workers are unique compared to other industrial workers in that they do not use any hand tools, they are seasonal workers, and the group of workers at the beginning of a season is usually a mixture of experienced and inexperienced workers. Additionally, the inability to predict when lifting and sorting will be done makes it difficult to establish an exercise program.

Occupational health problems in sorters are specific to the right wrist flexors, index and middle fingers, the right and left shoulders, and upper back areas. Infirm subjects are weaker in hand and finger strength at the beginning of the sorting season, deviate more frequently from the anatomically neutral upper joint position, and feel colder throughout the day comapred to healthy subjects. Infirm subjects also feel that their workstations are too low.

The following three recommendations were developed:

1) A video training program should be used to assist crew leaders in training sorters. The video should emphasize good work methods and proper hand motions.

2) An exercise-gymnastic rest/pause program should be introduced. Exercises should use resistance (such as rubber tubing or hand squeezing) to develop upper limb strength.

3) Administrative controls should be applied to keep the sorting sheds warmer.

A Stock Quality Assessment Procedure for Characterizing Nursery-Grown Seedlings[1]

S.C. Grossnickle, J.T. Arnott and J.E. Major[2]

Abstract.--Western hemlock and western red cedar seedlings were grown in a container greenhouse system under four different nursery cultural treatments. A stock quality assessment procedure was developed to characterize a seedling's drought avoidance (i.e. needle and root surface area, needle resistance, root growth capacity), drought tolerance (i.e. osmotic potential) and cold tolerance (i.e. frost hardiness, low temperature root growth capacity) capabilities developed through the various nursery cultural treatments. Results showed western hemlock seedlings in the short-day treatments and western red cedar seedlings in the moisture stress treatments had the best stock performance potential characteristics.

INTRODUCTION

Reforestation success depends largely on matching proper seedling stocktypes with field site conditions. To achieve reforestation success, foresters must be able to characterize seedling performance potential with expected field site environmental conditions (Sutton 1988). Thus, a predictive stock quality assessment procedure needs to simulate expected field site conditions to determine what morphological parameters and physiological characteristics are important for successful seedling establishment.

Stock quality assessment over the last decade has evolved to include a wide array of both morphological and physiological measurement procedures (see reviews by Sutton 1979, Chavasse 1980, Jaramillo 1980, Schmidt-Vogt 1981, Glerum 1988). Ritchie (1984) organized these assessment procedures into two areas called material attributes (i.e. direct measurements: nutrition, morphology, water relations, bud dormancy) and performance attributes (i.e. whole seedling response: root growth capacity, frost hardiness, stress resistance) and they were the focus of a workshop held at Oregon State University in 1984 (Duryea 1985a). Duryea (1985b) indicated that stock quality assessment procedures have come along way. However, further refining of measurement procedures is required. Specifically, a stock quality assessment program should consider physiological processes critical to seedling field performance, seedlings must be assessed under environmental conditions defined as critical to limiting field growth and survival and there must be a battery of tests to assess morphological and physiological factors important in predicting field performance success.

Within this study, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red cedar (*Thuya plicata* Donn)

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[1] Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, B.C. Canada

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seedlings, grown under four nursery cultural regimes, were examined for their capability to tolerate or avoid environmental conditions expected to influence establishment on a reforestation site. Based on stress tolerance/avoidance concepts of Levitt (1972), stock performance potential tests determined seedling's physiological and morphological response to optimal and suboptimal temperature and moisture conditions. Also measured were morphological parameters important in conferring desired stress avoidance characteristics. Only partial stock performance potential test results are presented in this paper, with further results to be reported in detail elsewhere. The actual effectiveness of a stock quality assessment procedure for predicting field survival and growth is part of an ongoing program funded by the Canada/British Columbia Forest Resource Development Agreement.

MATERIALS AND METHODS

Seedling Development

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seed (British Columbia Forest Service (BCFS Registered Seedlot no.3906; Lat. 48° 55" N, Long. 123° 55" W; elevation 340m) was stratified at 1° C for 4 weeks before sowing. Western red cedar (*Thuya plicata* Donn) seed (BCFS Registered Seedlot no. 7853; Lat.48° 50" N, Long. 124° 00" W; elevation 525m) was soaked in tap water for thirty-six hours prior to sowing. Both species were sown on March 2, 1987 in BC/CFS 313A styroblocks in a 3:1 mixture of peat and vermiculite with dolomite lime added to adjust the pH to 5.0 with coarse sand as a seed cover.

Seedlings were grown at the Pacific Forestry Centre, Victoria, B.C. (Lat. 48° 28" N). The greenhouse environment was maintained at a day/night temperature of 21/18° C, 50 percent relative humidity and natural light supplemented at night with high pressure sodium vapor lamps (i.e. 6µmol s^{-1} m^{-2}) to provide a sixteen hour photoperiod. Seedlings were watered and fertilized (i.e. 20-20-20 NPK with micronutrients) twice weekly (500 mg L^{-1}) and biweekly with the heptahydrate form of ferrous sulphate (155 mg L^{-1}).

Seedlings were grown under the above greenhouse regime until July 20, 1987 when mean seedling shoot height had reached 15.8 and 16.3 cm for western hemlock and western red cedar, respectively. At this point four dormancy development treatments were applied to one fourth of the seedling population for each species. The dormancy treatments were as follows:

1. Long-day wet (LDW); seedlings continued to receive the above greenhouse regime until the end of August.

2. Long-day dry (LDD); seedlings had the extended photoperiod as in the above stated greenhouse regime, but on July 20, 1987 the moisture stress treatment was initiated.

3. Short-day dry (SDD); seedlings, on July 20, 1987, had the moisture stress treatment initiated and had photoperiod reduced to eight hours on August 1,1987.

4. Short-day wet (SDW); seedlings continued to receive the above stated watering and fertilization regime until the end of August (as in 1) but had photoperiod reduced to eight hours on August 1, 1987.

All dormancy induction treatments were concluded on August 29, 1987, after which a regular watering and natural daylength regime was resumed. Fertilizer (10-51-16 NPK with micronutrients) was applied (500 mg L^{-1}) weekly until November and biweekly thereafter. Temperatures (day/night) were set at 20/10° C until 15 September, 17/8° C until 10 October, 15/5° C until 15 October, 13/4° C until 11 November, 10/3° C until 18 November and 8/0° C until seedlings were put into cold storage (2° C) on 11 January 1988.

In the moisture stress treatment, styroblocks were allowed to dry down to approximately 2.85 kg below their saturated weight before rewatering, plus fertilizing, to saturation and repeating the drying cycle. Throughout the six week period seedlings were subjected to six drying cycles. Seedling water status was monitored with predawn and noon xylem pressure potential readings during the moisture stress treatments. Xylem pressure potential readings were taken with a pressure chamber on six replicates from each treatment following procedures described by Ritchie and Hinckley (1975). Average predawn and noon xylem pressure readings for each species at the end of drying cycles were -0.3 and -0.7 MPa for western hemlock and -0.4 and -1.0 MPa for western red cedar, respectively. Though readings appeared to indicate little seedling water stress, many western hemlock

seedling shoots were wilted by the afternoon of the last day of each drying cycle. Thus,western hemlock shoot wilt was used as the indicator to end a drying cycle.

Statistical design of the greenhouse layout was a modified Latin Square. The four dormancy induction treatments were randomly assigned to four positions on the greenhouse benches. The two species were randomly assigned to opposite sides of each treatment block position. Over the course of the experiment styroblocks within a dormancy treatment were rotated every six weeks. Analysis at the end of the greenhouse operations showed no effect of bench location.

Seedling shoot height was nondestructively assessed (n=25) biweekly during the growing season, weekly during the dormancy treatment period and biweekly until October 23,1987.

Stock Performance Potential Tests

During January and February 1988 western hemlock and western red cedar seedlings in all treatments were assessed for physiological and morphological characteristics. Below is a brief description of the various stock performance potential tests.

Needle and root surface area

Surface area measurements were used to determine the needle transpiration area to root absorption area produced by all species/treatment combinations. Twenty-five seedlings from each species/treatment combination were dissected into workable shoot and root sections and processed through a Li-3100 (Li-Cor Inc.) area meter. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species (Steele and Torrie 1980).

Root growth capacity

Standard soil/pot test.--Seedlings from each species/treatment combination were placed in pots (8 replicates with 3 seedlings per pot) containing a 3:1 mixture of peat and vermiculite plus dolimite lime (2Kg m^{-3}). Pots were placed in a completely randomized design within environmentally controlled (i.e. 22/10° C day/night temperature, 55% relative humidity, 16 hr photoperiod at 200 µmol s^{-1} m^{-2}) growth rooms. Seedlings were grown for seven days, after which root development was assessed using Burdett's (1979) semiquantitative scale.

Hydroponic test.--Root growth capacity was also assessed for all species/treatment combinations in a hydroponic system. Seedling root systems were placed in a darkened aerated aquarium at a water temperature of 5° or 22° C and then seedlings were grown in a controlled environment growth room (i.e. 22° C air temperature, relative humidity 50%, 16 hr photoperiod at 650 µmol s^{-1} m^{-2}) for fourteen days. Root development was assessed in all species/treatment combinations (n=10) after fourteen days. The root classification system used for RGC testing was modified from the classification scheme outlined by Burdett (1979). The root classification categories are as follows: 0 = no roots, 1 = new roots but none over .5 cm, 2 = 1 to 3 new roots over 1 cm, 3 = 4 to 10 new roots over 1 cm, 4 = 11 to 30 new roots over 1 cm, 5 = 31 to 50 new roots over 1 cm , 6 = 51 to 75 new roots over 1 cm, 7 = 76 to 100 new roots over 1 cm and, 8 = > 100 new roots over 1 cm. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

Frost hardiness

Frost hardiness was assessed for all species/treatment combinations at -9,-12,-15 and -18° C test temperatures. Frost hardiness assessment was conducted by the B.C. Ministry of Forest and Lands, Surrey nursery. The method used was standard provincial procedure for the seedling browning test (Simpson B.C. M.o.F.L. personal communication). Seedlings from each species/treatment combination (n=40) were divided into two groups and assessed in a replicated experiment at the above mentioned temperatures. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

Osmotic potential

Pressure-volume analysis was used to determine osmotic potential at saturation and turgor loss point for all species/treatment combinations. Six replicates for each species/treatment combination were used for determination of pressure-volume curves with techniques described by Hinckley et al. (1980). Osmotic potentials were then determined by using a software program (Schulte and Hinckley 1985). Analysis of variance and Tukey's mean separation

test were used to determine treatment differences within a species.

Needle resistance

Needle resistance was used to determine cuticular development for all species/treatment combinations. Seedlings were potted in a sand culture system, placed in the controlled environment room (described in the root growth capacity section), well watered for five days and then allowed to slowly dry down. Seedlings were assessed for needle resistance during the time they were well watered and after continuously monitored base xylem pressure potentials had reached -1.5 MPa.

Needle resistance was measured in a foliage cuvette with a porometer (Li-6250, Li-Cor Inc.). For each measurement period, readings were taken on ten randomly selected seedlings from each species/treatment combination. Readings were taken one to three hours after the lights went off in the evening. At the end of the experiment, sample branches were removed and needle surface area was determined with a Li-3100 area meter. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

RESULTS

Growing season height growth

Western hemlock seedlings in the short-day treatments ceased shoot elongation by the end of the dormancy induction treatment, August 28, 1987 (Fig. 1). Seedlings in the long-day treatments continued shoot extension until early October. Short-day treatments had greater affect on the phenology of shoot growth than moisture stress treatments.

Western red cedar seedlings showed dormancy induction treatments to have no effect on shoot phenology or growth rate (Fig. 1). Short-day and moisture stress treatments did depress the rate of shoot growth, but not to any significant degree.

Needle and root surface area

Western hemlock seedlings in the LDW treatment had significantly more needle surface area than all other treatments (Fig. 2). Seedlings in the SDD and SDW treatments had the lowest and second lowest needle surface area, respectively. Root surface area was similar between all treatments.

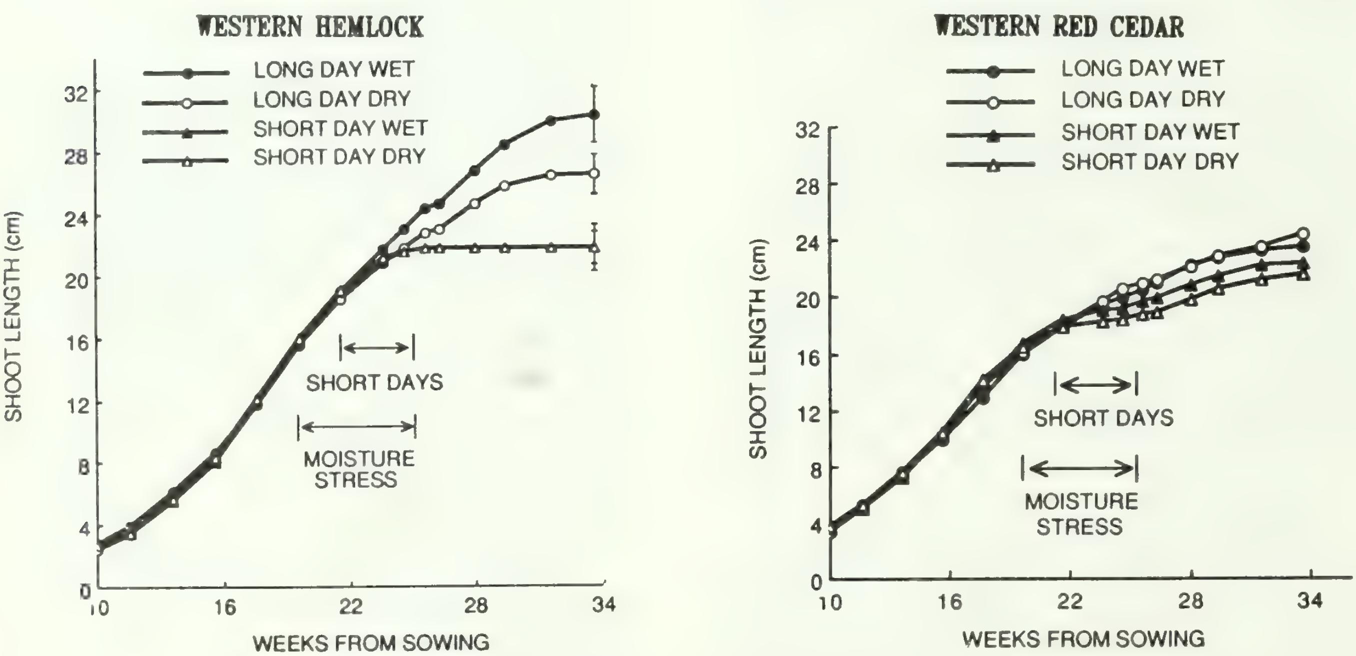

Figure 1.--Shoot length of western hemlock and western red cedar seedlings subjected to the dormancy induction treatments: a) long-day dry, b) long-day wet, c) short-day dry or d) short-day wet. Treatments (shown by arrows) were applied from July 20, 1987 until August 29, 1987. Vertical lines indicate ± 1 SE.

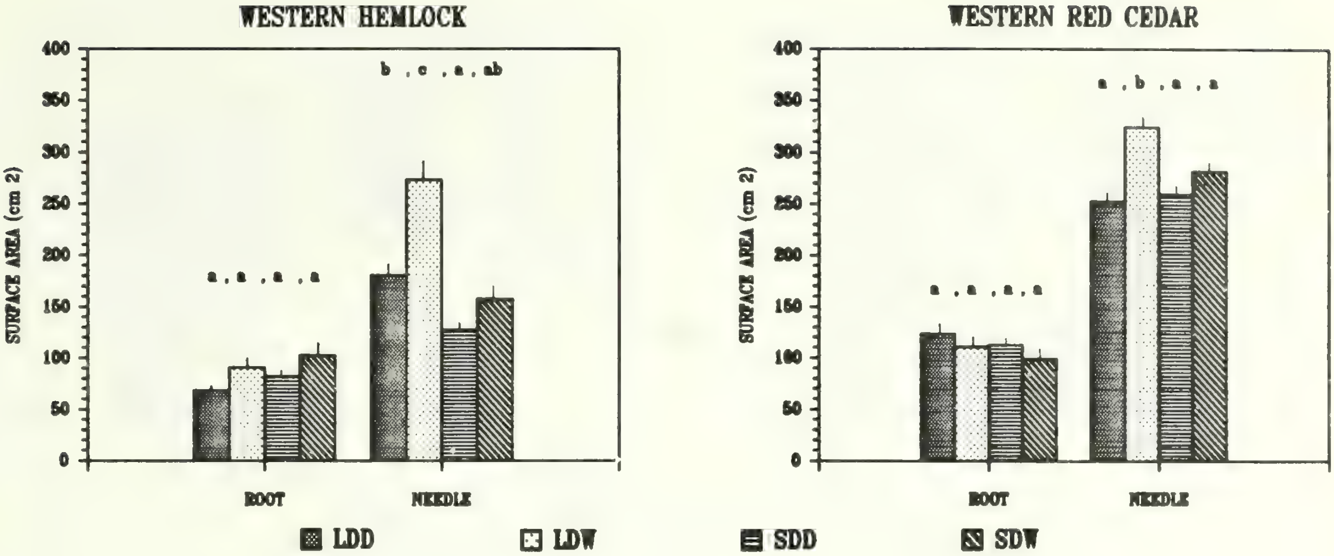

Figure 2.--Root and needle surface area (mean + SE) of western hemlock and western red cedar seedlings from the dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, for roots or needles, determined by Tukey's mean separation test (p=.05) are shown by different letters.

Western red cedar seedlings in the LDW treatment had the highest needle surface area (Fig. 2). Root surface area was similar between all treatments.

Root growth capacity

Hydroponic root growth capacity (RGC) data for western hemlock at 22° C shows the SDD treatment produced more new roots than all other treatments while the SDW treatment produced the least number of roots compared to other treatments (Fig. 3A). In the soil/pot system LDD treatment had a significantly lower RGC (Fig. 3B). At 5° C new root growth was greater in the short day treatments compared to the long day treatments (Fig. 3A).

Western red cedar hydroponic RGC data at 22° C shows new root growth was greatest in the LDW treatment and least in the SDW treatment (Fig. 3A). There were no treatment differences for seedlings tested in the soil/pot system (Fig. 3B). At 5° C new root growth was low in all treatments (Fig. 3A).

Frost hardiness

Western hemlock seedlings in the LDW treatment had the greatest amount of needle damage at all measured temperatures (Fig. 4). Seedlings in the LDD treatment showed the second highest percent of needle damage at lower temperatures (i.e. -15 and -18° C). Seedlings in the SDW treatment had the least amount of needle damage at lower temperatures.

Western red cedar seedlings in the LDW treatment had the greatest amount of needle damage at all temperatures (Fig. 4). At lower temperatures (i.e. -15 and -18° C), seedlings in the SDW treatment had needle damage comparable to the LDW treatment. At -18° C seedlings in the LDD treatment had the least amount of needle damage.

Osmotic potential

Western hemlock seedlings in the SDW treatment had the most negative osmotic potential, at saturated and turgor loss point, of all treatments (Fig. 5). Seedlings in the SDD treatment had a more negative osmotic potential at turgor loss point compared to LDD and LDW, but not as negative as SDW. The LDD treatment showed the least negative saturated and turgor loss point osmotic potentials of all treatments.

Western red cedar seedlings showed no statistically significant difference between treatments at both saturated and turgor loss point (Fig. 5). However,

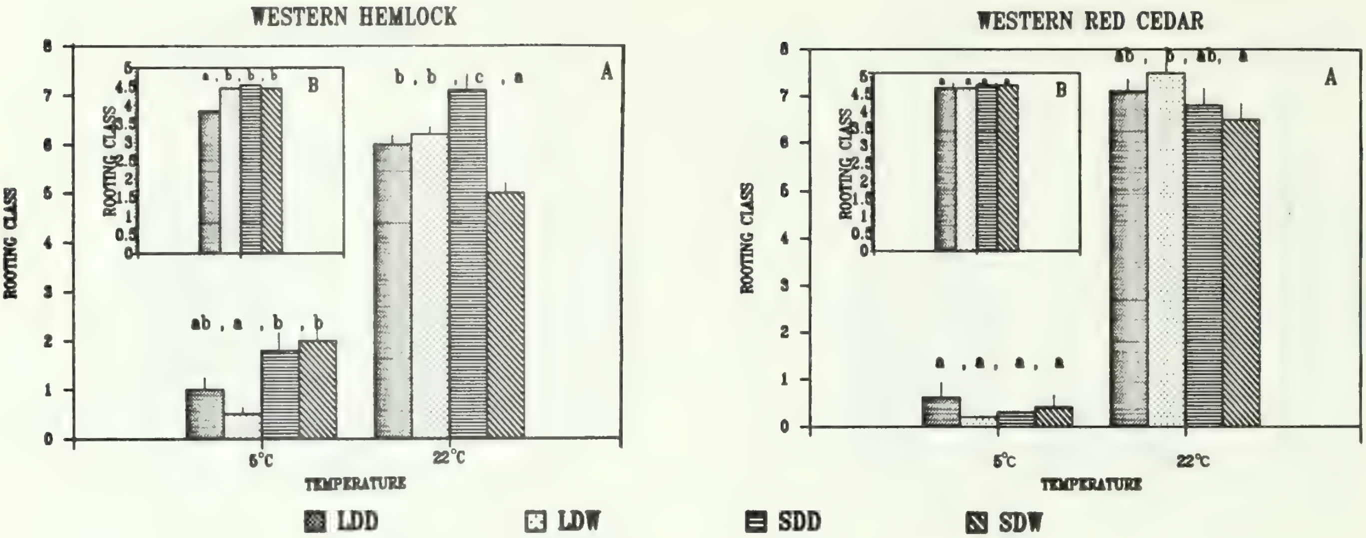

Figure 3.--Root growth capacity of western hemlock and western red cedar seedlings tested in hydroponic (A) or soil/pot (B) systems from the dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at a temperature, (mean + SE) in the hydroponic (A) system determined by Tukey's mean separation test (p=.05) are shown by different letters. Significant mean treatment differences in the soil/pot (B) system determined by Duncan's multiple range test (p=.01) are shown by different letters (SE of pop.+/-.16 for western hemlock and +/-.14 for western red cedar).

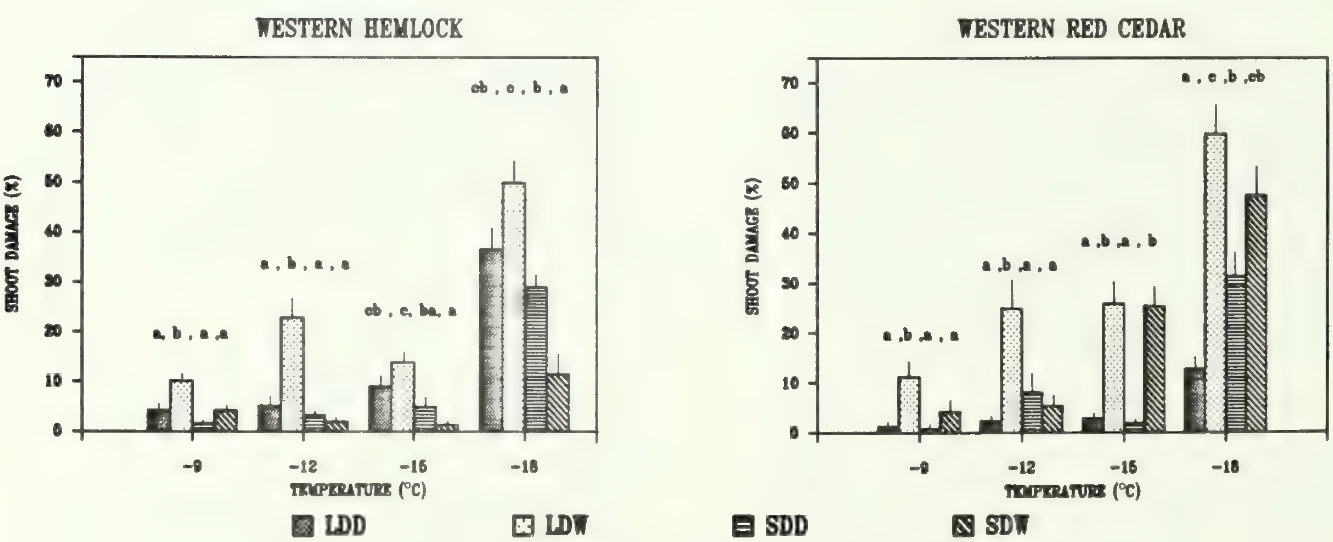

Figure 4.--Frost hardiness (mean + SE)of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at a temperature, determined by Tukey's mean separation test (p=.05) are shown by different letters.

the moisture stress treatment did cause a slightly more negative turgor loss point osmotic potential.

Needle resistance

Needle resistance of well watered western hemlock seedlings showed no difference between treatments (Fig. 6). Under water stress conditions needle resistance was highest in the LDW and LDD treatments. Seedlings in the SDW treatment had the lowest needle resistance values, while SDD was slightly higher, under water stress conditions.

Western red cedar seedlings, under well watered conditions, showed no difference in needle resistance between treatments (Fig. 6). Under water stress conditions seedlings in the SDD treatment had the greatest level of needle resistance. Seedlings in the SDW treatment had the second highest level of needle resistance under water stress conditions, while seedlings in the LDD and LDW treatments had the lowest levels of needle resistance.

DISCUSSION

Western hemlock seedling development in the nursery showed short-days, applied in early August, stopped shoot elongation, while moisture stress did not. These results substantiate conclusions from a similar experiment conducted in 1986 and reported at this meeting (Arnott et.al. 1988). Western red cedar seedlings seasonal shoot height did not show any response to nursery cultural treatments. Apparently the cultural treatments were not severe enough or were not the proper environmental cues to change shoot height development.

A balanced root/shoot ratio, or more accurately the absorbing surface to transpiring surface ratio, is important in reducing the development of high seedling water deficits caused when absorption lags behind transpiration (Kramer and Kozlowski 1979). This reasoning was used for defining root and needle areas as one of the stock performance potential tests. Results showed short-day and moisture stress treatments reduced needle surface area in both species. Western hemlock seedlings in the LDD, SDW and SDD treatment had progressively less needle area, respectively, while all moisture stress and short-day treatment combinations in western red cedar reduced needle area equally. Other research has shown that short-days (review of literature Arnott and Mitchell 1982), moisture stress (Kramer 1969) or both (D'Aoust and Cameron 1982, Macey and Arnott 1986) can alter seedling shoot morphology.

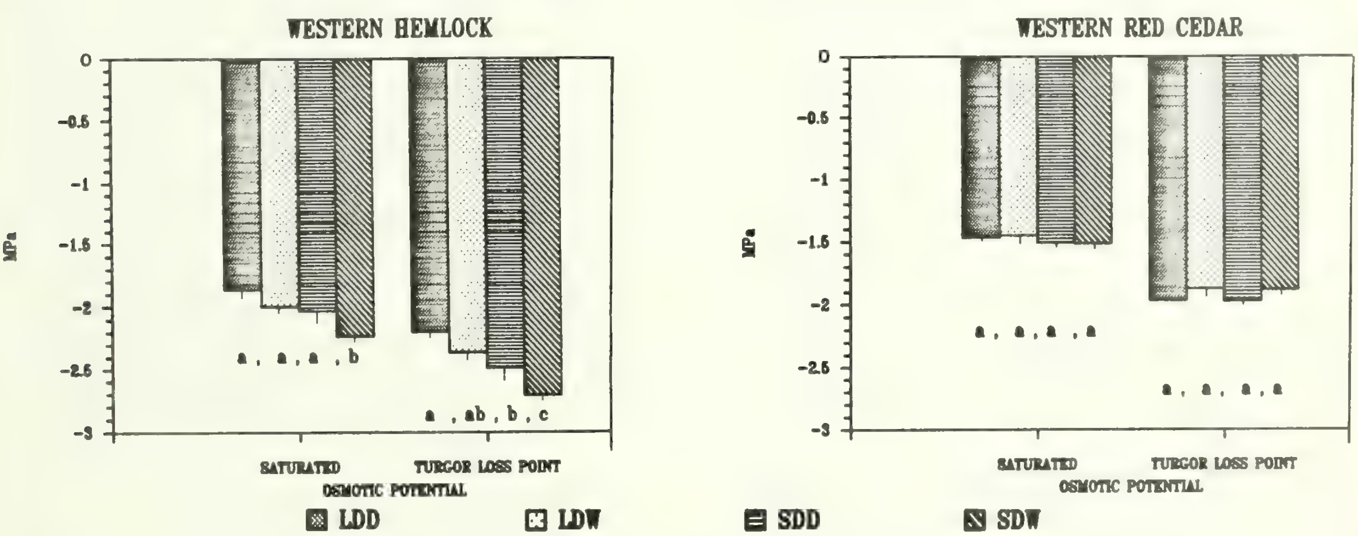

Figure 5.--Osmotic potential (mean + SE) of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at saturated or turgor loss point, determined by Tukey's mean separation test (p=.05) are shown by different letters.

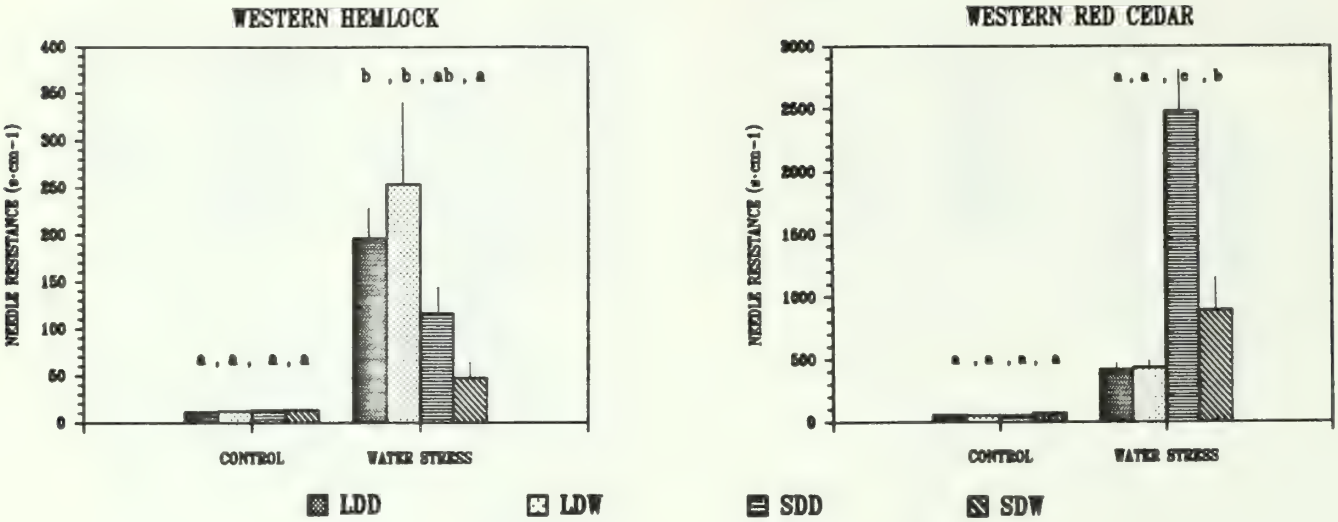

Figure 6.--Needle resistance (mean + SE) of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, within control or water stress, determined by Tukey's mean separation test (p=.05) are shown by different letters.

Root area in both species was similar in all nursery cultural treatments. This is contrary to the widely held belief that nursery cultural practices which stop shoot growth will result in a transfer of that seedling growth potential partially into root growth as well as into caliper and bud development (Ledig et al. 1970, Tinus and McDonald 1979). Upon examination of unreported morphological data, nursery cultural treatments did not alter caliper development in either species, but bud development in western hemlock was improved in the SDD and SDW treatments. Other researchers have also found that arresting shoot growth with nursery cultural practices did not result in reallocation of seedling growth potential into other areas of measurable seedling morphology (Heide 1974, Burdett and Yamamoto 1986, Arnott et al. 1988).

A quality seedling needs to have as high a root/shoot ratio as possible to ensure optimum field survival (Thompson 1985). Thus, short-day and moisture stress treatments in both species will improve the root/shoot ratio by reducing needle surface area development but not through enhanced root area development.

Results from root growth capacity (RGC) tests differed depending upon testing procedure. As expected, under optimal root temperature conditions the seven day soil/pot system produced fewer roots than the fourteen day hydroponic system in comparable species/treatment combinations. This difference between the two testing procedures was due to study length. Seedlings of both species tested at 22° C in the hydroponic or soil/pot system showed statistically significant treatment differences in RGC class. However, it is questionable whether this difference is biologically important because all RGC classifications were 5 or greater in the hydroponic system and 4 or greater in the soil/pot system. Outplanting studies comparing RGC with field survival have shown that above an RGC value of 1 to 3, field survival is usually greater than 80 percent (Burdett et al. 1983, Dunsworth 1986, Burdett 1987). Thus,seedlings from all species/treatment combinations produced in this study have the potential for good field survival.

However, it must be asked whether this testing method is a true representation of edaphic conditions a seedling encounters during early season planting. Seedlings are normally planted in late winter or early spring when soil temperatures are just above 5° C. An RGC test which examines root responses at low root temperatures might provide a stress tolerance test that more effectively predicts nursery cultural treatments influence on early root

growth in field planted seedlings. The low temperature test showed western hemlock seedlings in the SDW and SDD treatments produce RGC class values which have predicted good field survival in Pacific Northwest coastal conifers (Dunsworth 1986) compared to other treatments, while western red cedar seedlings did not show any treatment differences. Further work needs to be undertaken to determine whether a low temperature RGC testing procedure would provide useful information on seedling performance as it relates to field site conditions.

Frost hardiness testing was conducted on seedlings during the late winter to determine the level of frost tolerance provided by the nursery cultural treatments. Findings indicate that seedlings of both species in the LDW treatment had the least frost hardiness. Other researchers have also found that nonacclimatized seedlings will develop inadequate frost hardiness (Christersson 1978, D`Aoust and Cameron 1982, Colombo et al. 1982). Western hemlock seedlings developed greater frost hardiness in the short-day treatments, while western red cedar developed greater frost hardiness in the moisture stress treatments. Research has shown short-day treatments can improve frost hardiness (Timmis and Worall 1975, Christersson 1978, D`Aoust and Cameron 1982, Colombo et al. 1982), while moisture stress treatments can improve frost hardiness in some studies (i.e.Douglas-fir, Tanaka and Timmis 1974, Blake et al. 1979) but not in others (i.e. black spruce, D`Aoust and Cameron 1982). This difference in species frost hardiness response to cultural treatments needs to be considered when developing a nursery growing regime.

Interestingly, the combination of short-day and moisture stress was not as effective in conferring frost hardiness as just the short-day treatment in western hemlock and the moisture stress treatment in western red cedar. Work with black spruce has shown this same response (D`Aoust and Cameron 1982). This lack of synergism between short-day and moisture stress to improve frost hardiness indicates that the combined influence creates an environment too stressful for full frost hardiness development.

Osmotic adjustment in western hemlock seedlings was greatest in the SDW followed by the SDD treatment. Western hemlocks' osmotic adjustment in the short-day treatment is an interesting phenomenon. Dickson and Nelson (1982) working with cottonwood found short-day treatments used to induce dormancy increased the sugar levels in leaves. Sugars and organic acids have been shown to cause osmotic adjustment in a number of species (Osonubi and Davies 1978, Sharp and Davies 1979). Thus, the short-day treatment in western hemlock could have promoted increased sugar and organic acid production resulting in increased osmotic adjustment.

Western red cedar seedlings showed only a slight osmotic adjustment in the LDD and SDD treatments. Previously reported work with conifer seedlings has shown greater osmotic adjustment in response to moisture stress (Kandiko et al. 1980, Seiler and Johnson 1985, Bongarten and Teskey 1986, Grossnickle 1988). For western red cedar the problem seemed to be that the drying cycles were not long enough to develop sufficient seedling water stress for greater osmotic adjustment to occur. Further work needs to be conducted to develop moisture stress treatments that will provide maximum osmotic adjustment in western red cedar with minimum impact on other desirable seedling attributes.

Needle resistance is a combination of stomatal, mesophyll and cuticular resistances (Hinckley et al. 1978). As long as the stomata are partially open they are the primary factor influencing needle water loss. However, if the stomata are forced to close (e.g. via seedling water stress and/or darkness) the subsequent measurement of needle resistance would represent the cuticular resistance of the needles. This was the working hypothesis developed for the needle resistance stock performance potential test.

Western hemlock under water stress conditions (i.e. -1.5MPa) resulted in the LDW and LDD treatments having the greatest level of needle resistance. At first glance this would seem to be contrary to the working hypothesis. However, if needle resistance data is examined in conjunction with the osmotic potential data, it shows that needle resistance measurements were taken on seedlings that had never reached the turgor loss point (i.e. range from -2.2 to -2.7 MPa). Thus, these needle resistance measurements were taken at a medium level of water stress for western hemlock. In this condition the SDW and SDD treatments responded to the moderate water stress by keeping their stomata open slightly during the dark phase. Studies have shown that conifers

stomata, under low to moderate moisture stress, can remain open during the dark (Running 1976, Blake and Ferrell 1977).

Western red cedar seedlings showed high needle resistance in the SDD and SDW treatments at the -1.5 MPa measurement time. Western red cedar seedlings at this measurement time had daytime seedling water stress exceed their turgor loss point (i.e. range from -1.8 to -1.95 MPa) which resulted in stomatal closure in all treatments. Thus, when stomata were closed, the cuticular resistance was highest in the SDD and SDW treatments. Seedling water stress will produce seedlings with thicker more cutinized needles (Rook 1972), while short-day treatment in combination with low temperature have been found to reduce seedling transpiration rates (Christersson 1972). Short-day and moisture stress treatments seem to reduce needle water loss in western red cedar.

CONCLUSION

The intent of this stock quality assessment procedure was to develop a testing system that would characterize drought tolerance and avoidance plus frost hardiness and cold tolerance in western hemlock and western red cedar seedlings. This first approximation shows that there is merit to this approach because it provided a good overall picture of how seedlings, treated with different nursery cultural regimes, will respond to potentially deleterious field conditions. Further refinements of the needle resistance and low temperature RGC tests are required. Once refinements are incorporated, foresters will be able to determine seedling performance potential as it relates to both optimal and deleterious field site environmental conditions.

The findings reported show daylength and moisture stress nursery cultural treatments, as applied in this study, can influence the physiological and morphological characteristics of western hemlock, but only some morphological and physiological characteristics of western red cedar seedlings. Western hemlock seedlings in the SDW and SDD treatments and western red cedar seedlings in the LDD and SDD treatments had the best overall stock performance potential grade from the stock quality assessment procedure developed in this study. Further work is required to develop nursery cultural treatments that properly modify the seedlings physiological and morphological characteristics desired for improving establishment on reforestation sites.

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Using Frost Hardiness as an Indicator of Seedling Condition[1]

Jay R. Faulconer[2]

Abstract.--Knowing the frost hardiness of conifer seedlings is of benefit to nursery managers and seedling users even if the potential for actual frost damage is not of major concern. Examples are presented illustrating the ability of comparative hardiness testing to reveal variation in seedling phenology brought about by genetic, cultural, and environmental factors. Implications for the timing of cultural practices and lifting windows are discussed.

Introduction

The physiological condition of conifer seedlings during the lifting and planting season is of critical importance to the success of reforestation efforts. This subject has received much emphasis in recent years, reflected by ongoing efforts to estimate seedling quality using a variety of physiologically based tests, such as root growth potential (RGP), stress tests, dormancy release index (DRI), frost hardiness (FH), and others (Duryea, 1985). Although these tests are founded upon sound physiological theory, their success in accurately predicting stock performance in operational settings has been mixed. One reason for this is that quality tests can only assess potential stock performance. Even with high quality seedlings, poor handling or severe environmental stresses may still result in performance problems.

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Another source of uncertainty has been the fact that seedling physiological condition may change between the time of testing and the time the seedlings are lifted or planted. Seedling condition, of course, changes continually throughout the year; this is reflected in the seasonal development of RGP, FH, and other seedling attributes. When a seedling lot is tested one time during the planting season, the results give a "snapshot" indication of the general condition of the seedlings on the date tested. This approach has proven to be satisfactory for the routine screening of large numbers of seedling lots, and for identifying lots with severe quality problems. However, because of the continual changes that seedlings undergo, a detailed understanding of seedling physiology can be obtained only through a "motion-picture" approach, that is, tracking seedling conditioning through tests conducted at intervals during the lifting/planting season. This can be done with several tests, either alone or in combination. Ritchie (1980) showed how RGP changes seasonally, rising from low levels in the fall to a midwinter peak, and then falling again in spring. Frost hardiness follows a similar pattern, and both appear to be related to the dormancy cycle. For the past several years, International Paper has used the physiological tracking approach for assessing proper lifting dates for seedling lots grown at its Kellogg Nursery. Each of the major tests has been utilized in this context; this paper will focus on the usefulness of frost hardiness testing as an

indicator of seedling condition at various times throughout the planting season. The interplay of seedling genetics, nursery cultural practices, and environmental factors, specifically chilling hour accumulation, will be discussed with regard to their influence on hardiness development, and by implication, on proper lifting window.

Background

Reforestation is most successful when seedlings are handled at the time of maximum stress resistance. Stress resistance is an abstract term which is difficult to quantify. It includes such attributes as drought tolerance and frost hardiness, and is generally considered to be linked to the seedling dormancy cycle. While dormancy and stress resistance are difficult or time consuming attributes to quantify, it is relatively easy to measure frost hardiness. Although frost hardiness testing has received much attention in the past, interest has usually been limited to assessing the potential for frost damage to seedlings. As part of International Paper's seedling monitoring program, we have adopted as a working hypothesis that, as frost hardiness increases, overall resistance to stresses of all kinds also increases (Faulconer and Thompson, 1985). The basis for this assumption is the fact that frost hardiness develops as a result of metabolic changes such as cessation of active growth and physiological dehydration of various seedling tissues, indicative of a lowered state of metabolic activity for the entire seedling. Additionally, years of observations have indicated that maximum reforestation success is achieved in midwinter, when frost hardiness is at its peak, regardless of whether any frost damage has occurred. Tracking the seasonal development of frost hardiness thus becomes of interest even if the potential for actual frost damage to seedlings is not of major concern.

The rate at which seedlings enter dormancy and begin to develop resistance to stress is controlled by three categories of factors: the genetic background of the seedling lot, nursery cultural practices, and other environmental influences such as photoperiod and cool temperatures. If one or more of these factors differs between seedling lots, the timing and rate of their hardiness development may also differ, resulting ultimately in varying optimum lift dates for the seedlings. If the development of frost-hardiness is followed beginning early in the fall, divergent trends in hardiness development can be identified early enough to be used as a guide for lifting schedules and for assessing the storability of seedlings.

Methods

Frost hardiness testing is begun in the fall, as soon as hardening commences. Samples are lifted at biweekly intervals usually beginning on or about October 1. Each sample lot is divided into three or four subsamples, which are subjected to a gradient of increasingly severe simulated whole plant frosts in a programmable freezing chamber. Temperatures are chosen at which 20%, 50%, and 80% mortality is expected. After freezing, seedlings are placed in a greenhouse for five days to allow damage symptoms to develop. Damage to cambium, buds, and needles is then evaluated visually using the "browning" method. For each temperature run, percent mortality is estimated based on the severity of damage to the various tissues. Mortality is then plotted against temperature, and the LT-50, or lethal temperature for 50% of the seedling sample, is interpolated from the resulting line. The LT-50 is the term from which the hardiness development curves are derived. For a more detailed description of this and other methods of evaluating frost hardiness, see Burr et al (1986) and Schuch (1987).

As the season progresses, the frost hardiness development curve for each lot is plotted on a chart. This enables direct comparison of the hardening trends between seedling lots. Hypothetical example curves showing typical divergence of hardening trends are illustrated in figure 1. In this example, on any given sample date there is a spread of several degrees C in the LT-50s between these lots. If a target hardiness of, for example, -15 C is desired before lifting, then a comparison such as provided by figure 1 indicates a difference of several weeks for the opening of the lifting window between lots.

The remainder of this paper provides actual examples of divergent hardening trends and discussions of the causes of divergence. All examples are for coastal Douglas-fir grown at International Paper Kellogg Nursery. This data has been collected as part of our routine seedling monitoring program conducted each fall and winter. Frost hardiness monitoring ends as the seedlings are lifted and sent to the field; for that reason the following hardiness development curves end during midwinter.

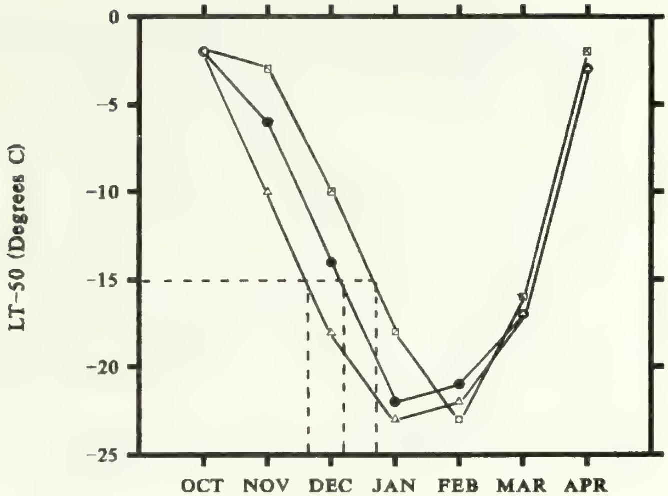

Figure1. Typical divergence of frost hardiness development trends between three seedling lots.

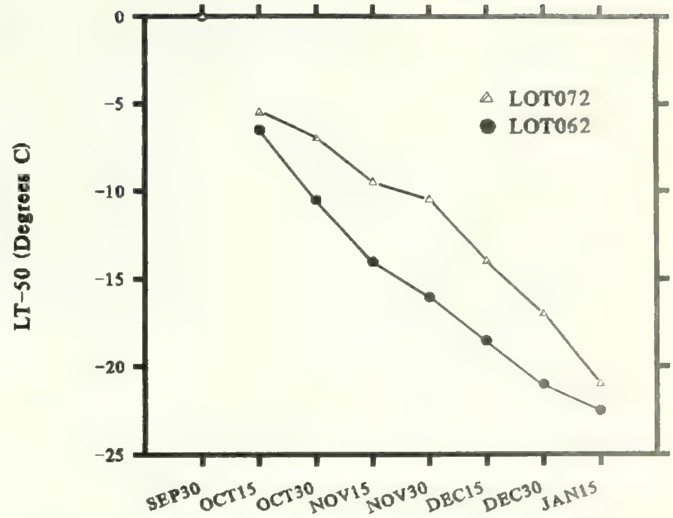

Figure 2. Comparison of frost hardiness development for two 2+0 lots from different seed sources (Oregon zones 072 and 062).

Genetic Variation

Jenkinson (1984) discussed at length the phenomenon of seed source lifting window. By plotting several years of plantation survival data versus lift date, for numerous seedling lots from the USFS Humboldt Nursery, he established that different seed sources have varying safe lifting windows. Because all seedlings were from the same nursery, receiving essentially the same cultural practices and exposed to the same climatic conditions, the factor responsible for lifting window variation was evidently seed source genetic variation. If the mechanism by which the genetic component influences lifting window is by determining the rate and timing of hardiness development during the fall, then variation in seed source lifting windows should be predictable by comparative frost hardiness testing of the various seed sources.

Figure 2 illustrates the frost hardiness development curves for two seedling lots at Kellogg Nursery in 1987-88. Both lots were 2+0s and were subjected to identical cultural practices and climatic conditions during both years in the nursery (in fact, the sample areas for the two lots were in adjacent beds). Seedlings from zone 072 0.5 (southern Oregon coast) lagged dramatically in hardiness development as compared to those from 062 1.0 (mid-Oregon coast). On any given sample date, the hardiness of the 072 lot, in terms of LT-50, was from 3 to 6 degrees C behind the 062 lot. In terms of lifting schedules, a more useful way to interpret this data is to say that the 072 seedlings were two to three weeks behind in hardiness development.

The tendency of seedling lots from the southern Oregon coast to lag behind more northerly or inland lots in hardiness development has been observed repeatedly for each year frost hardiness tests have been conducted. Jenkinson (1984) also found that the lifting windows for provenances from this general region consistently open later than for other sources evaluated. For two seed sources similar in origin to those illustrated in Figure 3 (072 Powers and 061 Alsea), he discovered a spread in the opening of the lifting window nearly identical to the spread between the frost hardiness development curves of the corresponding Kellogg lots. This suggests that fall hardiness development trends and seed source lifting windows are directly related. If so, then frost hardiness testing would offer nursery managers a substantial shortcut for establishing lifting windows for various seed sources.

Nursery Cultural Practices

Nursery cultural practices can have a great impact on the induction of dormancy in seedlings, and on the subsequent development of hardiness. Practices such as the withholding of nitrogen or induction of moisture stress are designed to cause the

cessation of active growth in preparation for the fall and winter. These practices interact with, and to an extent sometimes override, the genetic component controlling dormancy development, potentially resulting in an additional source of variability in hardening trends between seedling lots.

The most important phenological effect of cultural manipulation of nursery seedlings is probably the timing of final budset, which in nurseries can occur anytime from midsummer to autumn. Frost hardiness tests indicate that hardiness development can be strongly affected by the timing of budset. Figure 3 illustrates the FH development curves for two seedlots from Kellogg Nursery. In this example, the two lots were sown with the same seedlot (zone 252 1.0) in the spring of 1986. Lot 1 was sown for 2+0 seedlings, whereas lot 2 was lifted after the first year and transplanted for 1+1 production. The genetic background of the lots was identical, as was nursery environment and climate. The divergent hardening trends between the lots must therefore be due to the variation in cultural regimes for the two stock-types. The 1+1 lot reached target height early in the second year, and the seedlings were "shut down" by mid-July through moisture stress treatments. For the 2+0 lot, in contrast, height control was achieved partially through top-mowing, which though effective, can delay final bud set. As a result, the timing of budset differed significantly for the two lots.

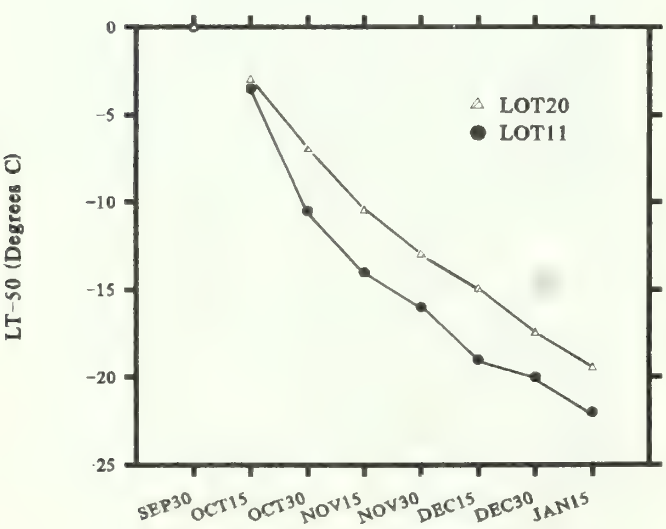

Figure 3. Comparison of frost hardiness development trends for 2+0 and 1+1 seedlings sown with the same seedlot (Oregon zone 252 1.0).

Lavender and Stafford (1984) demonstrated the importance of early budset in order for seedlings to properly respond to the cool temperatures which condition seedlings in the fall and early winter. They showed that a period of mild, short days occurring after budset was necessary for subsequent cool weather to be fully effective in satisfying chilling requirement. The frost hardiness curves for these two lots indicates that early budset will also hasten the subsequent development of hardiness. This suggests that cold hardiness and fulfillment of chilling requirement are physiologically linked, which was hypothesized by Ritchie (1986). It would appear then that the timing of the lifting window is determined by the efficiency with which seedlings respond to fall and winter chilling, which can be measured by rate and degree of frost hardiness attainment.

Environmental Conditions

Besides genetics and nursery cultural practices, the third major variable affecting seedling hardiness development is the nursery climate, especially exposure to cool temperatures. As discussed above, genetics and cultural practices interact to produce seedlings that are either more or less predisposed to efficiently respond to chilling. From then on, the amount of chilling actually received is the most important determinant of hardiness development.

Nursery climate varies geographically between nurseries, and annually within a single nursery. One commonly used method to deal with this variability is to quantify the duration of cool temperatures experienced by seedlings. Hours during which the temperature is less than a specified minimum are defined as chilling hours, and the accumulated number of such hours experienced by seedlings is used as a guide for predicting seedling condition.

Although use of chilling hour accumulation is easy, inexpensive, and provides an instantaneous assessment of seedling condition (one can always know the number of hours accumulated on any given day), sole reliance on chilling has several disadvantages. First, as discussed earlier, seedling lots which have been exposed to the same amount of chilling may be in very different stages of hardiness development. Secondly, there is apparent disagreement regarding the effective temperature range of a chilling hour. Jenkinson (1984) defines it as being less than 10 C, whereas Ritchie (1986) uses temperatures below 6 C.

Other researchers have used only temperatures between 0 and 5 C in the belief that very cold temperatures retard the physiological processes driven by chilling. Finally, there is uncertainty as to the effect of interruptions of chilling accumulation by unseasonably warm temperatures.

The type of uncertainty which can result from sole reliance on chilling hours as a guide is illustrated in figures 4 and 5. Figure 4 represents graphically the accumulation of chilling hours (defined here as hours cooler than 6 C) at Kellogg Nursery for two consecutive years, 1985-86 and 1986-87. Due to mild weather in the fall of the second year, chilling accumulation lagged far behind that of the first year. The oft-cited 300 hour minimum requirement before safe lifting may commence was not reached until mid-January, about six weeks later than the previous year. Figure 5 compares frost hardiness development for the two years for zone 252 2+0 Douglas-fir. Although development in 1986-87 did lag behind that of the previous year, the delay was not nearly so dramatic as might have been expected from the chilling hour data. One possible explanation is that cultural practices differed somewhat between the two years and offset the difference in chilling. More likely is that in 1986, temperatures slightly outside the arbitrary range, which did not count toward the cumulative total, were still effective in stimulating hardiness development and in satisfying chilling requirement.

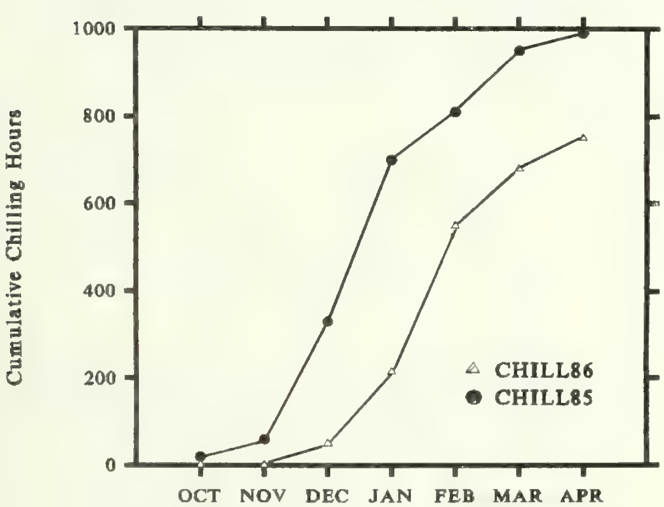

Figure 4. Chilling hour accumulation at Kellogg Nursery for 1985-86 and 1986-87.

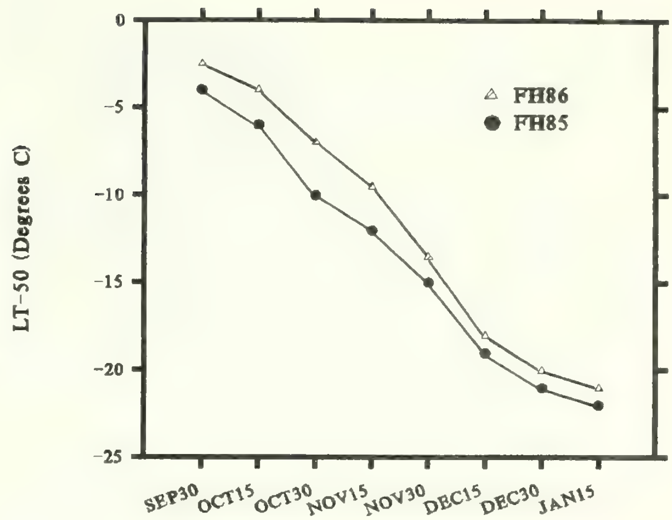

Figure 5. Comparison of frost hardiness development trends for zone 252 1.0 2+0 seedlings in 1986-86 and 1986-87.

Because of the variability between the large numbers of seedling lots produced at most nurseries, and because chilling hours are apparently poorly defined, reliance on chilling hour accumulation alone as an indicator of seedling condition will likely result in an overly generalized and potentially inaccurate assessment of the status of nursery seedlings. Different species and seed sources may have different chilling requirements in terms of number of needed hours, and they may be responsive to different temperature ranges. Attempting to establish guidelines which would account for the multitude of seed sources, and for the variability introduced by cultural practices, would be a monumental task. Much easier is to simply measure the seedlings' integrated response to the genetic, cultural, and climatic factors responsible for their hardiness development.

Frost Hardiness and Storage

The preceding sections have illustrated how frost hardiness testing can detect differing rates of hardiness development between seedling lots. At this point it is still uncertain what hardiness level should be attained before lifting, storage, and planting may proceed safely. However, some preliminary work measuring the effects of cold storage on frost hardiness has provided some clues. Figure 6 illustrates a portion of a typical hardiness development curve for Douglas-fir 2+0 seedlings tested during the fall and early winter of 1987. On each lift date, one sample was tested immediately; another

was placed in cold storage to be retested on the next lift date. The objective was to determine whether hardiness continued to develop in storage, and to compare the hardiness of stored seedlings with those which remained in the nursery. For the first lift dates, when seedlings were still in the early stages of hardiness development, an apparent loss of hardiness occurred during storage. Later, as the hardiness of seedlings in the nursery beds deepened, it appears that an ability to maintain hardiness in storage developed. Viewing frost hardiness as an indicator of overall seedling physiological status, this suggests that the physiological stability of seedlings in storage increases as hardiness deepens. In this example, it appears that lifting and storage before attainment of an LT-50 of approximately -15 C will result in a loss of seedling vigor.

Other observations have indicated that storage of seedlings lifted after significant dehardening has begun also results in further loss of hardiness (Ritchie 1986). It is generally recognized that the quality of seedlings lifted either too early or too late will decline in storage. By measuring the amount of hardiness lost in storage, it should be possible to quantify "too early" and "too late" in terms of LT-50 on the lift date.

In contrast to these results, Burr (1989) found that interior Douglas-fir continued to harden or even reversed dehardening when placed in cold storage, regardless of the hardiness level at the time storage commenced. However, this work was conducted with containerized seedlings which remained upright and undisturbed in

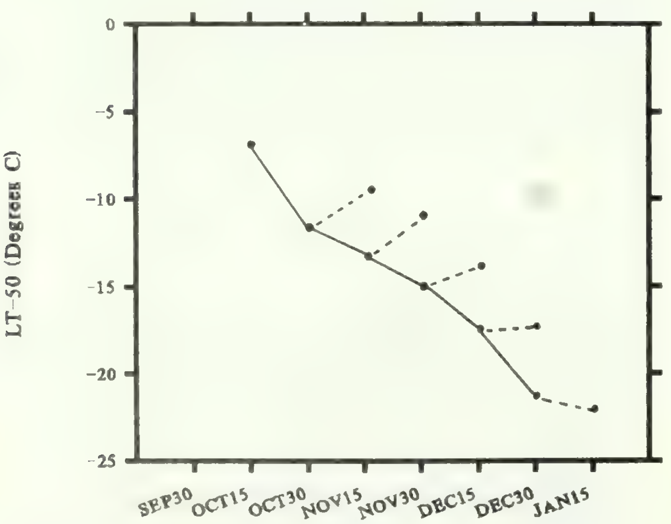

Figure 6. Effect of cold storage on frost hardiness development of coastal Douglas fir. Dotted lines connect LT50 points from fresh samples with stored samples from the same lift date.

the containers during the storage treatments. The storage treatments discussed in the previous paragraph involve bare-root seedlings which have been lifted from the beds and stored horizontally in tightly packed paper bags, similar to operational storage practices at a bare root nursery. The contrast in effect on frost hardiness development between the two differing storage treatments suggests that the shock associated with bare root lifting and storage prevents or retards further physiological changes during storage which would result in continued hardiness development. The fact that undisturbed seedlings which are placed in storage are capable of further physiological development serves to emphasize the importance of minimizing the stresses associated with bare root lifting, and to conduct the lifting when resistance to stress is at its peak.

Conclusion

The foregoing observations regarding the value of frost hardiness testing as an indicator of seedling condition have resulted from several years of International Paper's operational seedling monitoring program. More formal research is needed to confirm the hypotheses presented in this paper and to further investigate the relationship of frost hardiness to other physiological attributes of nursery seedlings. Specifically, the correlation between frost hardiness and overall stress resistance should be more firmly established, and more information is needed regarding the effects of storage on frost hardiness. In the meantime, however, there is little doubt that comparative frost hardiness testing can reveal significant differences between the phenological cycles of different seedling lots, with important implications for the timing of cultural practices and lifting operations.

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Monitoring Viability of Overwintering Container Stock in the Prairies — An Overview of a Five Year Lodgepole Pine Study[1]

Ian J. Dymock[2]

Abstract. Overwintering viability of first year containerized lodgepole pine seedlings was monitored using a series of morphological assessments, dormancy tests and freezing tolerance(cold hardiness) tests. Results presented outline the phenology of dormancy and cold hardiness development. The impact of environmental factors is discussed in relation to the overwintering success.

INTRODUCTION

This presentation will provide some insight into the study results obtained from our research on monitoring viability of overwintering container stock. We have been working with five species of conifer seedlings that are grown for reforestation purposes on the Canadian prairies. At this time, I will restrict my talk to our lodgepole pine data.

In a production nursery situation, where containerized stock is to be overwintered outdoors, nursery personnel can rely on the shortening natural photoperiod, during the latter part of the summer, to initiate the onset of dormancy in their seedlings. The gradual reduction in the day and night temperatures triggers the gradual development of cold hardiness.

While the induction of dormancy and cold hardiness is achieved under ambient conditions, it often must be achieved in a relatively short period. This is particularly true for nurseries in cold temperate regions, where early frosts can be a serious problem.

It is therefore imperative, for the nursery personnel to have a good understanding of the basic physiology involved in successful overwintering of container seedlings. It is also important for staff to have rapid and reliable tests at their disposal in order to monitor the development of dormancy and cold hardiness in their seedlings.

Our study on overwintering physiology had three purposes then, in light of the preceding discussion:

1. To evaluate methods for the determination or testing of seedling dormancy and cold hardiness.
2. To investigate the relationships between terminal buds, the stem(cambium) and roots, and the phenology of dormancy and cold hardiness development during overwintering.
3. To provide a better understanding of the basic physiology of overwintering in conifer seedlings that could aid in the development of improved nur sery management practices.

The results presented will provide you with an overview of five year's efforts in this study.

MATERIALS AND METHODS

Rearing and sampling schedules

Seedlings of lodgepole pine(*Pinus contorta* var. *latifolia* Engelm.) were reared in Spencer-Lemaire Fives according to the methods of Carlson(1983), using schedule 2 for hardiness zone 3.

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Details of the rearing and sampling schedules can be found in Dymock and Dendwick(1987, 1988).

Morphological assessments

The morphological assessments made at the initial time of sampling included the following: height and root collar diameter measurements; visible damage assessment of seedling shoots, needles, buds and roots; shoot and root fresh(FW) and oven dry weights(DW); calculation of seedling shoot/root ratios(S/R) based on fresh and dry weights; and the calculation of shoot and root moisture content.

Dormancy tests

Dormancy tests were conducted on stems(cambium) using the oscilloscope-/square wave deformation(SWD) technique of Ferguson, Ryker and Ballard(1975), but using the coding system of Dymock and Dendwick(1987).

Root dormancy was monitored using the root growth capacity(RGC) method of Burdett(1979) and the scoring system for estimating the numbers of new roots over one cm in length.

Shoot(bud) dormancy was monitored by determining the time to bud break (TTBB) using conditions similar to those used in the RGC test. Seedlings remained in the greenhouse until all buds had broken and seedlings were fully flushed. The average number of days to complete bud break(TTBB) were then calculated.

Freezing tolerance tests

Initial tests were carried out during 1983-84 using rapid freeze/thaw cycles. Whole seedlings in containers were placed in cold rooms or freezers set at -5C, -10C and -15C for 6, 24, or 168 hr. Control seedlings were left at 20C. At the designated times, seedlings were rapidly brought to room temperature, subjected to oscilloscope/SWD testing and then moved to the greenhouse.

Four weeks later, shoots and roots were assessed for visible damage. Shoot and root assessments were added to yield a seedling survival rating. Seedlings rated -5 or higher, were considered survivors, while those rated below -5 had little chance of survival.

The rating system used to assess visible damage to shoots and roots, was modified from the one previously reported by Dymock and Dendwick(1987). It has been modified to more accurately reflect degrees of damage, and is as follows:

Rating	Symptoms of pine shoot damage
0	No visible damage to the shoot terminal, stem or needles.
-1	Terminal bud alive; no apparent stem damage; < 20% dead needles.
-2	Terminal bud alive; no apparent stem damage; 20-50% dead needles.
-3	Terminal bud alive but shows some damage; 50-90% dead needles.
-4	Terminal bud dead; most of upper stem and lateral branches dead; < 10% live needles, most of them emerging from lower stem area.
-5	Shoot completely dead; no living tissue present.

Rating	Symptoms of pine root damage
0	More than 10 new roots > 10 cm long; many white root tips.
-1	4-10 new roots > 10 cm long.
-2	1-3 new roots > 10 cm long.
-3	Some new roots, but none > 10 cm long; some white root tips.
-4	No new roots or white root tips; some loss of turgor in old roots.
-5	No live roots; roots dark brown to black in colour; no turgor; bacterial/fungal growth evident.

Supplemental freezing tolerance tests were carried out during the 1984-85, 1985-86 and 1986-87 seasons. Whole seedlings in containers were subjected to -5C, -10C and -15C for 24 hr periods only. Controls were maintained at +5C.

After 24 hr, seedlings were rapidly thawed and brought to room temperature. Conductivity testing of shoots and roots was done using the method of Colombo, Webb and Glerum(1984) but with those modifications reported by Dymock and Dendwick(1987). Seedlings were also potted and returned to greenhouse conditions for visible damage assessments four weeks later.

From the conductivity test results, the mean percent relative conductivities of shoots and roots were calculated. The index of injury for each set of shoots and roots from each freezing temperature was then calculated according to Colombo et. al.(1984).

Environmental parameters

Weather records were collected over each overwintering period. These include the period from the time seedlings were moved outdoors to the shadeframes, until the following spring.

Shoot temperatures(at bud height), root plug temperatures, and air temperatures at 1.8 metres, were routinely

monitored using a Campbell Scientific CR-7 Micrologger equipped with copper-constantan thermocouples.

Long term records, and corroborating daily records from the closest local weather stations, were obtained, from the Canadian Climate Control Centre of Environment Canada(Downsview, Ont.).

RESULTS

Morphological assessments

Seedling height and root collar diameter measurements from all five study seasons are shown in figure 1. In all cases, height growth was completed prior to late August. Root collar diame-

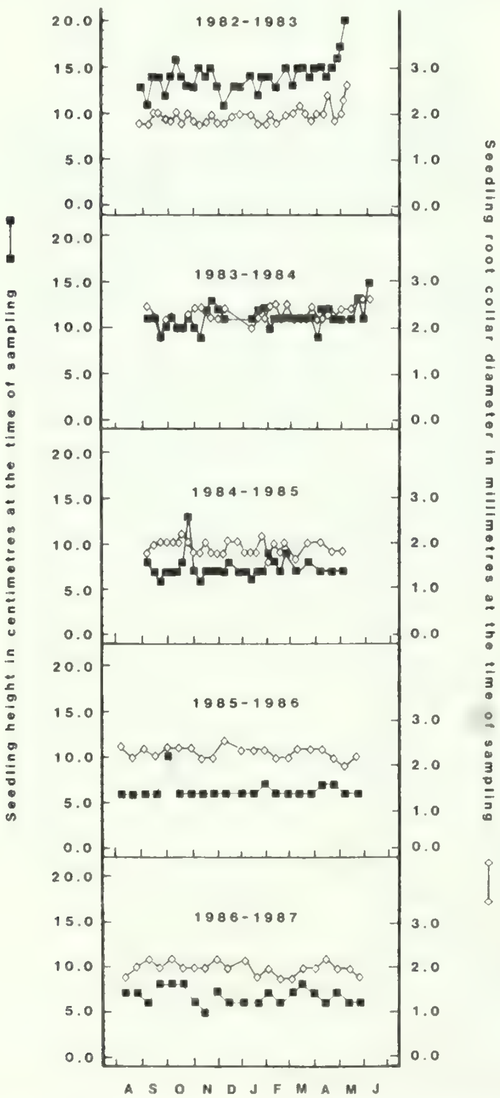

Figure 1. Comparative seasonal changes in height and root collar diameter over five overwintering periods.

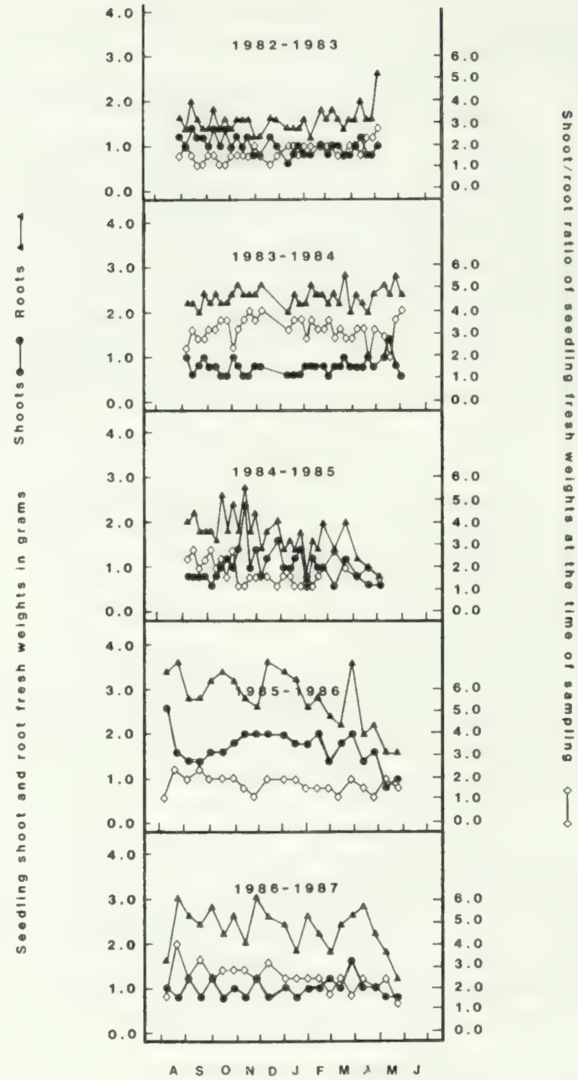

Figure 2. Comparative seasonal changes in shoot and root fresh weights and shoot/root ratio of fresh weights over five overwintering periods.

ter continued to increase for some time yet into September. No appreciable changes in either parameter would be expected again until spring, as seedlings begin to flush.

Height began to increase again in the springs of 1983 and 1984 but not in each of the following three years(fig. 1). Similar results are seen for root collar diameter measurements(fig. 1).

Parallel results can be seen in figure 2 for the shoot and root fresh weights and the S/R(FW) ratios. In the latter three seasons, pronounced drops in mean shoot fresh weights are quite evident.These began at different times, but always closely following the early

loss of snow cover from the seedlings (data not shown).

There was no comparable decline in either the shoot(or root) dry weights (data not shown). However, the shoot FW loss that is seen in figure 2, is clearly seen in figure 3 as a loss in shoot water. This was observed in each of the 1984-85, 1985-86 and 1986-87 seasons. The rapid loss of shoot water content closely paralleled the loss of snow cover from the shoots(data not shown).

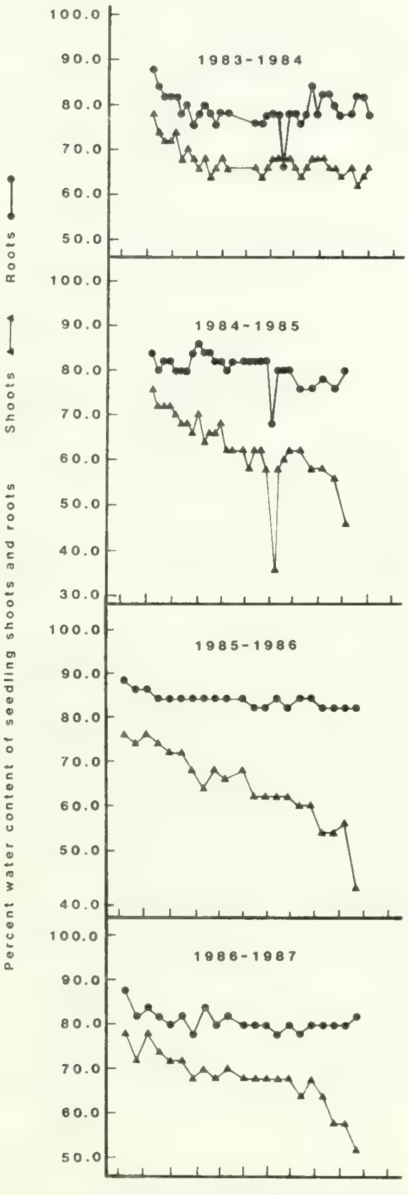

Figure 3. Comparative seasonal changes in shoot and root moisture content over four overwintering periods.

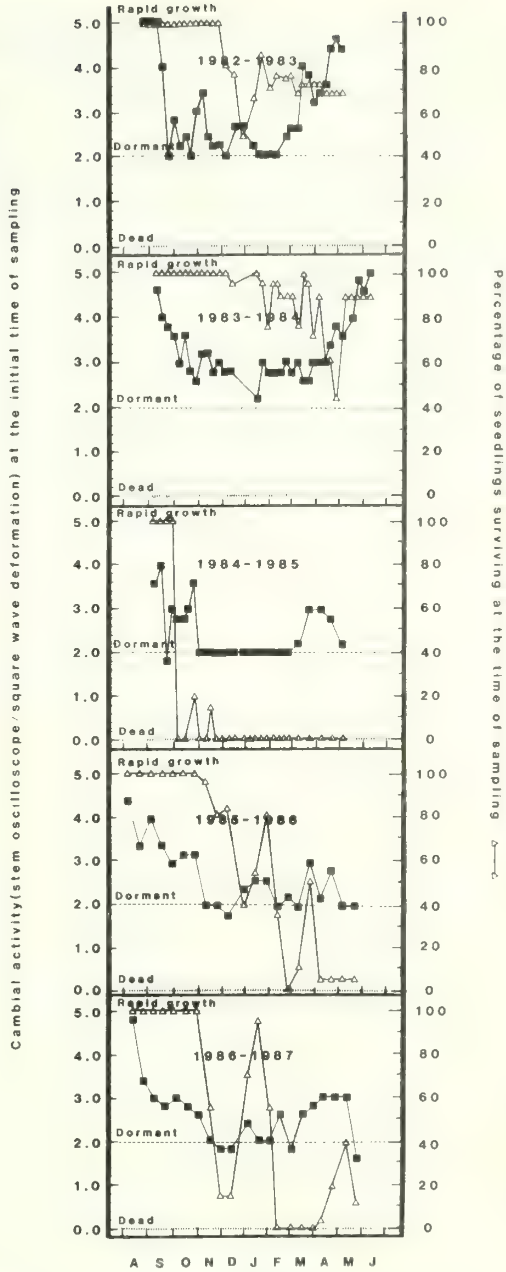

Figure 4. Comparative stem activity and percent seedling survival over five overwintering periods.

Dormancy tests

Stem(cambial) activity declined during the fall of the year, although this was quite variable(fig. 4). Stem activity was quite variable during the winter months. Only during the 1984-85 season did stem activity appear to remain dormant for a prolonged period.

Seedling survival throughout the sampling periods, was highly variable,

as seen in figure 4. It generally showed a mid-winter decline during most of the study seasons, and began to increase again towards the spring in some but not all seasons.

Root dormancy, as monitored by the RGC test, dropped with time during the early fall months, but this was quite variable(fig. 5). During 1983-84, there was a slow increase in RGC as seedlings came out of dormancy in the late spring. However, during each of the three succeeding seasons, little sustained root activity was observed after mid-winter.

Shoot(bud) dormancy, as monitored using the TTBB test, showed a much more regular annual pattern as seen in figure 5. The TTBB was very high initially in each season and declined to an early minimum by November of each year. Secondary increases in TTBB occurred later during most winters before dropping off prior to the spring flush.

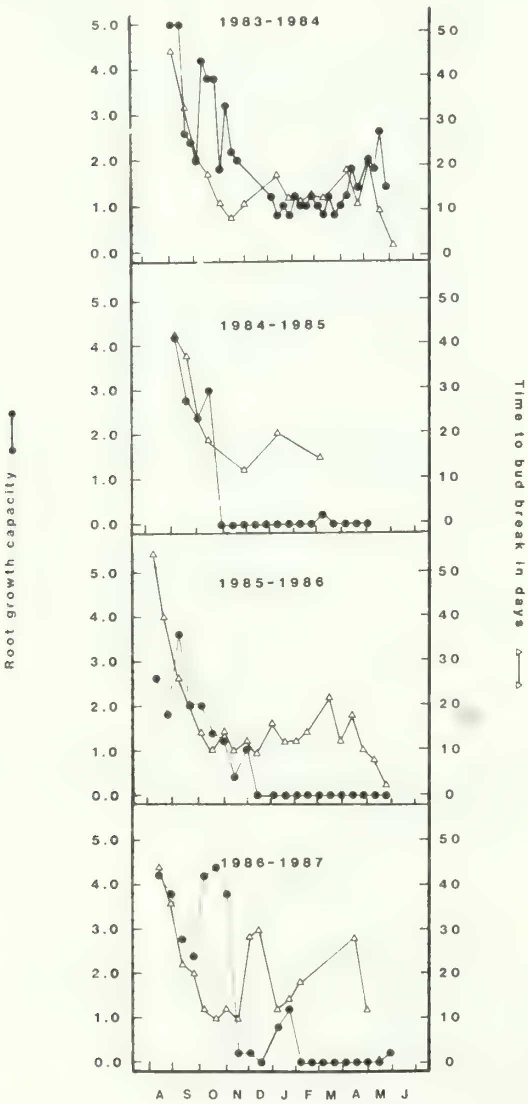

Figure 5. Comparative root growth capacity and time to bud break over four overwintering periods.

Freezing tolerance tests

Results of initial freezing tests during 1983-84, are shown in figure 7. The seasonal trends in stem activity, and freezing tolerance of seedling shoots and roots are seen quite clearly.

Rigorous nonparametric statistical testing was conducted on the results. Temperature comparisons within the duration classes were conducted for each parameter(ie. oscilloscope/SWD trace; shoot damage; root damage). Results showed that as the freezing temperature decreased, the damage increased, giving the ordering as: Controls<-5C<-10C<-15C for all classes(data not shown).

Similar analyses of duration comparisons within the temperature classes were conducted. Initial tests indicated that there was an ordering effect for duration with respect to shoot damage for each temperature(6hr<24hr<168hr), but only for roots at -5C. Duration had no significant effect on stem activity.

Further analysis indicated that duration had a significant effect on shoot damage between 6 and 168 hr at -5C and -10C, but had only a marginal effect at -15C. There was only a significant duration effect on root damage at -5C (data not shown).

During the 1984-85, 1985-86 and 1986-87 seasons, supplemental freezing tolerance tests were conducted for 24 hr only. The results are shown in figure 7. It can be seen that seedlings in these three years were unable to reach the same levels of hardiness that were reached by seedlings from the same seedlot, during the 1983-84 season(fig. 6).

Results from conductivity testing of shoots and roots indicated that roots were slower to harden than shoots. It was also shown that the roots did not achieve the same levels of hardiness to the lower test temperatures(data not shown). This was also seen, but to a lesser extent, in figure 7 with respect to shoot and root visible damage.

Environmental parameters

Figure 8 shows the weather records for each of the overwintering seasons in this study. In the first portion of this

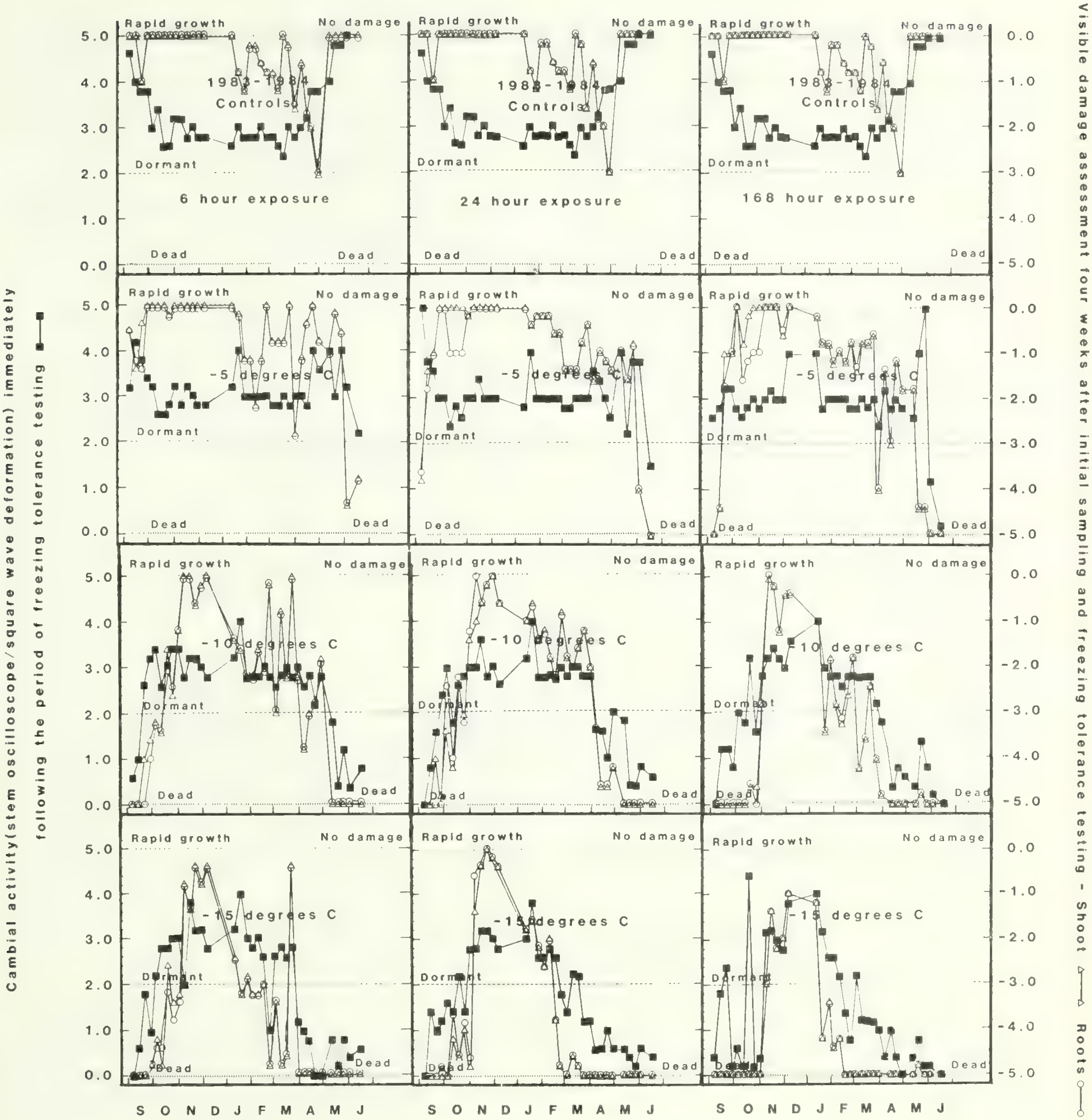

Figure 6. Influence of freezing temperatures and duration of exposure on stem(cambial) activity and visible damage to shoots and roots during the 1983-84 overwintering period.

figure(fig. 8a), are plotted the values for the mean daily minimum and maximum temperatures for the 30 year period from 1941-1970. Also shown are the daily extreme minimum and extreme maximum temperatures from 100 year records to 1981.

The mean annual period from first to last frost, growing-degree days, and hardening-degree days, derived from the 1941-70 period, are also shown(fig 8a). The daily range in temperatures, from minimum to maximum, are indicated by the

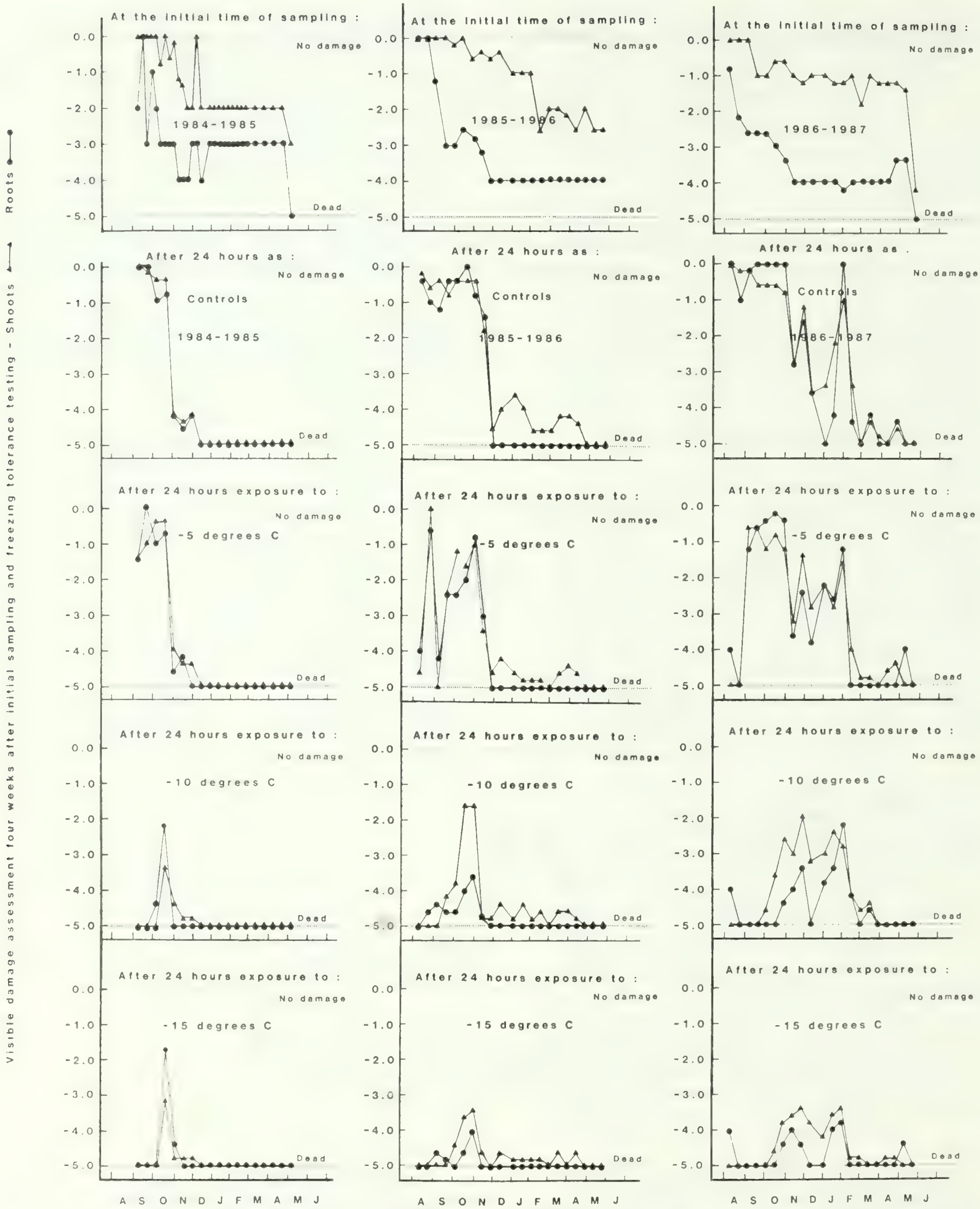

Figure 7. Comparative influence of freezing temperatures on visible damage to shoots and roots over the 1984-85, 1985-86 and 1986-87 overwintering seasons.

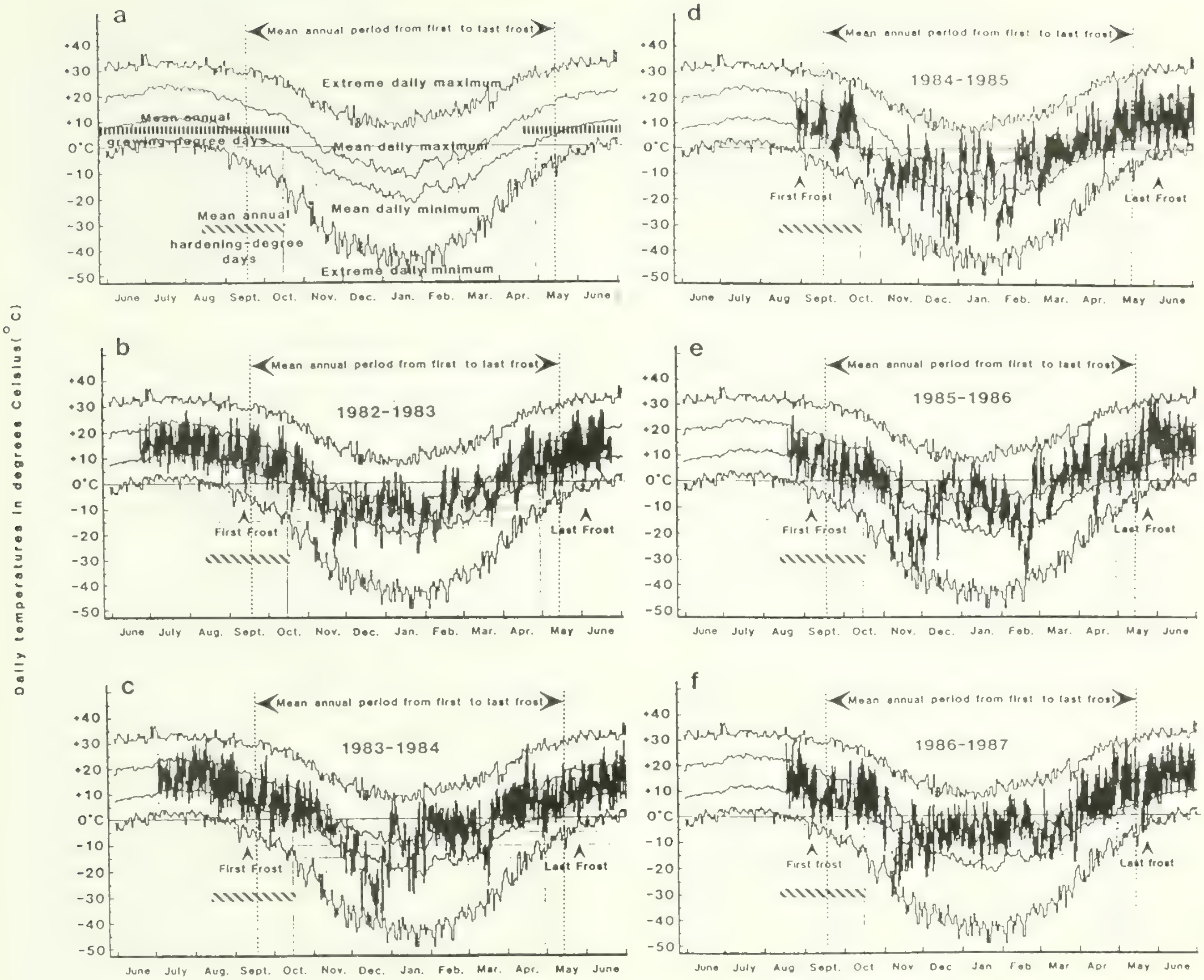

Figure 8. Mean daily temperature data for the 1941-70 period for Edmonton, Alberta and the daily records for each overwintering season.

vertical black bars that overlay the means(fig. 8b-8f). They begin on the day that seedlings were moved outdoors, and continue through to the end of the sampling season the following spring.

These records, and the impact of the environmental parameters are the primary focal point for the remainder of this presentation.

DISCUSSION

The principle feature that can be discerned from the weather records in figure 8, is that the 1982-83, 1983-84 and 1986-87 seasons were closest to normal (ie. the 30 year means) during the critical hardening period.

This period can be considered to occur from the time that the seedlings are moved outdoors, to the middle of November(fig. 8). At this point, for 1983-84, seedling shoots and roots were approaching their most hardy state, relative to -15C(fig. 6)

There are 295.8 cumulative hardening-degree days that can be expected between August 14 and October 18. The cumulative hardening-degree days for each season, and the percentage deviations from the expected mean were:

1982-83	336.5(+13.8%)
1983-84	270.5(- 8.6%)
1984-85	172.5(-41.7%)
1985-86	191.5(-35.3%)
1986-87	281.3(- 4.9%)

During the first year of freezing tolerance testing(1983-84), the number of hardening-degree days just fell short of the expected mean(-8.6%).

For each of the next two seasons in 1984-85 and 1985-86, seedlings were subjected to temperature variations that were frequent and unusually severe. They often occurred during the early hardening stages(figs. 8d and 8e). Warming cycles also presented problems as will be discussed shortly.

For 1984-85, the large drop in the hardening-degree days was likely due to the numbers and severity of early frost events that occurred during late August and throughout September(fig. 8d). They were followed by very severe conditions and early snows in mid-October that persisted well into the winter months.

These conditions greatly decreased the potential number of hardening-degree days for the seedlings. They were more than sufficient to arrest any further development of cold hardiness, as has been shown in figure 7. There was also a significant impact on stem activity and seedling survival(fig.4), and on bud and root dormancy(fig. 5). The end result, was a crop that had insufficient time to properly achieve full dormancy and cold hardiness.

Similar extremes were experienced in the 1985-86 crop. The conditions that occurred during the critical hardening period significantly retarded the full development of a satisfactory overwintering state.

This was further exacerbated by unusually mild conditions during the second half of the winter(fig. 8e). This in turn contributed to the shoot damage that became apparent(figs. 2 and 3) with the loss of snow cover. Survival then dropped rapidly(fig. 4), due to the loss of water from the shoots.

In both years, there was little capacity for any new root growth(fig.5). This was partially due to the failure of roots to sufficiently harden during the fall, due to the numbers and severity of early frosts. Shoots of those seedlings brought indoors for testing, continued to flush, at least initially. They did perish, however, due to their inability to generate new roots, caused by the earlier freezing damage(fig. 5).

In 1986-87, hardiness developed along normal lines(fig. 7), but did not reach the levels observed in 1983-84 (fig. 6). This crop started to decline in survival during late January 1987. This was at the time when very warm temperatures developed, and snow cover was lost. These conditions were prevalent throughout the rest of the winter and into the spring.

The now exposed shoots suffered from rapid water loss and winter drying, with the advent of above freezing temperatures(fig. 8f). The still frozen roots were unable to replace the water lost from the shoots(fig. 3), due to increased metabolic activity, and seedling mortality increased(fig. 4).

SUMMARY AND CONCLUSIONS

In the latter three seasons, the failure of each overwintering crop was due to two factors. Initially, these were due to the early and severe frosts. These were then coupled with warming temperatures during the latter part of the winter, which precipitated increased seedling mortality due to winter drying of exposed shoots.

Each test utilized in this study was useful in monitoring the progress of the seedlings as dormancy and cold hardiness developed. Each provided a good evaluation of seedling status, for the parameter under investigation, at each of the sampling dates.

When this point information was combined over a season and compared to the environmental data, then reasons for the success or failure of the crop became apparent. This type of testing and analysis, then, is of paramount importance for nurseries that overwinter container crops outdoors.

Point sampling lets staff monitor viability of the stock and should allow for precautionary protective measures to be taken, in advance, when adverse weather conditions are expected. Similar sampling and testing immediately following exposure to severe conditions, also allows for a fairly rapid diagnosis of damage that may have been incurred.

These tests and the information derived from them, then, would provide nursery management with an additional tool to aid in decisions on the ultimate fate of the stock.

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Root Growth Potential as an Indicator of Outplanting Performance: Problems and Perspectives[1]

Thomas D. Landis and Susan G. Skakel[2]

Abstract.--Root growth potential (RGP) tests have not always proven to be good predictors of outplanting performance under operational conditions. Problems include sample collection, handling, and storage; testing environment; root growth rating system; species differences; outplanting site conditions; and development of an accurate and precise prediction equation. Unless better prediction equations can be developed or threshold points defined, RGP tests should be used primarily as a test of seedling vitality, not relative vigor.

INTRODUCTION

Seedling quality is one of the most widely discussed topics in nursery and reforestation science these days. The 1984 Evaluating Seedling Quality workshop focused new attention on the subject, and the workshop proceedings are considered a primary reference (Duryea 1985). Following this workshop, many nursery managers and reforestation specialists became inspired and either built their own seedling testing equipment or initiated a regular program of seedling quality analysis by independent testing facilities.

Of all the various seedling quality tests, root growth potential (RGP; also called root growth capacity - RGC) is probably the most widely-used, and can be defined as a measure of the ability of a seedling to produce new roots when growing in an ideal environment (Ritchie 1985). The RGP concept is intuitively attractive - more new roots means better survival and growth (Sutton 1980). RGP tests are currently being used by many reforestation foresters as a way to predict the outplanting performance (either initial survival or subsequent growth) of a group of nursery seedlings.

After several years of trying to analyze and apply the results of RGP tests, however, a certain backlash has developed. Many foresters are finding that there is considerable variability in their test results, and that they are not always good predictors of field survival and growth. Binder and others (1988) present results of large-scale operational trials that attempted to predict outplanting performance with RGP tests, and discuss the limitations of this practice. One of the problems is that many nursery managers and foresters tend to oversimplify some of the basic concepts inherent to RGP tests. Actually, the problem may not be the tests themselves, but how they are applied. The situation is analogous to using a pipe wrench to tune-up the carburetor on your car - there is nothing wrong with the tool itself, only the way that you are trying to use it.

USING RGP TESTS TO PREDICT OUTPLANTING PERFORMANCE

RGP tests from research laboratories have generally been found to correlate relatively well with seedling outplanting performance, either survival or growth after outplanting. Burdett (1987) provides a listing of the principal studies.

One way to introduce the relationship between RGP tests and outplanting performance is to examine an array of RGP test results, and outplanting performance over a variety of real-life situations. The following table presents different combinations of RGP test results taken at two different times: a pre-shipping test at the nursery and a

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pre-planting test in the field. These test results can be arrayed against various outplanting performance scenarios:

	RGP Test Results		Outplanting
	Pre-shipping	Pre-planting	Survival
1.	GOOD	GOOD	POOR
2.	POOR	GOOD	GOOD
3.	POOR	POOR	GOOD

In situation 1, nursery stock was in good condition at the nursery, it was shipped, handled and stored properly, and planting quality was good. However, site conditions were not conducive to good survival. Even under the best seedling quality and handling procedures, seedlings may not survive under extreme site conditions.

The stock in situation 2 was in poor condition at the nursery. Handling and site conditions were ideal, however, resulting in good survival in spite of poor stock quality. It is also possible that the nursery test was in error; sampling procedures, shipping timeliness and quality, or errors in testing are problems that can confound RGP test results.

Situation 3 has posed a dilemma for many foresters. The reason for poor RGP test results, but good field performance is simple, however. Outplanting performance is a function of two factors: seedling quality and outplanting site conditions (Sutton 1987). Seedlings of poor quality will perform much better on a good site, with ideal outplanting and seasonal growing conditions, than they will under stressful site conditions. Under ideal site conditions, even seedlings with low RGP will survive and grow well.

PRACTICAL SIGNIFICANCE OF RGP TESTS

On an operational level, RGP tests can have two different interpretations:

1. Qualitative. RGP tests are a good indicator of seedling vitality - seedlings that are able to produce a reasonable amount of new roots are obviously alive (Burdett 1987). The RGP test is actually a modification of the traditional "pot test", in which seedlings were planted in containers and placed in a favorable environment to see if they were alive (Binder and others, 1988). As such, RGP tests provide a simple "YES-NO" answer about the viability of the sample seedlings at the time of the test.

2. Quantitative. The second interpretation of an RGP test is that the amount of new roots is somehow related to outplanting performance. To make this interpretation, the new root production must be quantified according to some relative root growth scale, and then a mathematical relationship established with outplanting performance (Sutton 1987). As mentioned earlier, the assumption that more new root growth means better performance than less new new root growth is a seemingly reasonable hypothesis. In the following section, we will discuss some of the problems with this assumption.

REASONS THAT RGP TESTS MAY NOT CORRELATE WELL WITH OUTPLANTING PERFORMANCE

1. Sampling considerations. The number of seedlings used in an RGP test is really quite small and may not be representative of the population at large. A sample of 60 seedlings, which is the number usually required by seedling testing laboratories, is only 0.12% of a moderately-sized seedlot of 50,000 seedlings.

The sample must also be randomly collected from throughout the seedling population. It is relatively easy to collect a random sample when the seedlings are still in the seedbed or on the grading table, but sampling becomes more difficult once the stock has been packaged and stored. It is operationally difficult to sample from bagged seedlings, because a number of bags must be accessed, opened, and the sample collected from throughout the bag, not just from the top layer of seedlings. Sampling during frozen storage would be almost impossible.

RGP test results are only representative of the larger population at time the sample was taken. As soon as the samples are collected, they are under a different set of environmental conditions than the original seedling population, and many things can happen to the original seedlot from the time of lifting until they are outplanted. The RGP rating of a seedlot should remain relatively stable in cold storage, although it has been shown to vary (Sutton 1980), most likely in seedlots that were not completely dormant at the time of lifting.

The timing of RGP tests deserves special mention. RGP test scores will vary with the physiological status of the seedling, particularly in response to its environment. If you are interested in outplanting performance, therefore, the best time to sample the seedlot is as close to the time of planting as is operationally possible. Tests performed on seedlings at the time of lifting will probably not accurately reflect the condition of the seedling at time of planting, although they are useful to evaluate nursery cultural practices.

RGP tests are not instantaneous, either. Most RGP tests take several weeks for handling, shipping and processing so it may take as long as 4 to 6 weeks to receive test results.

2. Poor handling after sample collection. Again, once the samples are collected they are being subjected to different conditions than the original seedling population. Poor handling

practices, poor packaging for shipping to the testing facility, delays during shipping to the testing facility, or a prolonged storage period at the testing facility can seriously affect the test results. Seedlings submitted for RGP tests should be kept cool, packaged in insulated containers, and shipped to insure that they will arrive at the testing facility within 48 hours. In one operational RGP testing program, poor sampling or storage were implicated as the reason for confusing tests results on one sampling date (Zensen unpublished manuscript).

3. Failure to maintain "ideal" environmental conditions during the RGP test. Because it measures potential root growth, RGP tests should be run under greenhouse-like conditions. Burdett (1979) recommends a standard ambient environment of:

Day temperature	30° C (86 $^{\circ}$F)
Night temperature	25° C (79 $^{\circ}$F)
Relative humidity	75%
Daylength	16 hr.
Light intensity	15,000 lux

This standard environment is for the atmosphere surrounding the seedling shoot, however, not necessarily the root. Root environments can vary considerably between the three different RGP testing environments: potted seedlings, hydroponic (aerated water), and aeroponic (mist chamber). Because of the low cost of materials and ease of operation, the hydroponic ("fish tank") RGP test is used by many reforestation foresters conducting their own tests at field locations (Palmer and Holen 1986). Although results from the 3 different test environments have been correlated under laboratory conditions, there may be operational problems in maintaining a proper test environment at remote field sites. Temperature and aeration of the water in the tank are extremely important, as is excluding light from the roots. Root aeration may be especially important with species that are particularly sensitive to flooding injury.

4. The problem of quantifying new root growth. Unfortunately, the root system is the most difficult part of a seedling to observe and measure. Because roots are so fragile and can grow rapidly, measuring new root growth during RGP testing is even more of a problem. Sutton (1987) discusses the difficulty of quantifying RGP and some of the various measurement systems that have been used.

Many people are using Burdett's root rating scale for quantifying the amount of new root growth in RGP tests (Burdett 1979). Because this rating system offers a considerable savings of time and effort in evaluating new root growth and was also one of the first to be published, it has been widely accepted as the standard:

Root Growth Rating	Number of New Roots
0	None
1	Some, none > 1 cm long
2	1 to 3 > 1 cm
3	4 to 10 > 1 cm
4	11 to 30 > 1 cm
5	31 to 100 > 1 cm
6	101 to 300 > 1 cm
7	300 + > 1 cm

Use of this one scale to rate new root growth has obvious advantages:

* It is much easier and faster to count new roots than to measure them.

* Speed of root growth may be more indicative of seedling vigor than total amount of new roots, so this 7-day rating system may be better than other 28-day tests.

but it also has some serious limitations:

* This root rating system was not developed using any morphological or physiological data relating the amount of roots that are necessary for a seedling to successfully become established and grow.

* Different seedling species produce new roots at different rates. The 7-day rating system apparently worked well under laboratory conditions for coastal Douglas-fir [Pseudotsuga menziesii (Mirb.)Franco] and a number of other northwestern conifers (Burdett 1987), but some species, such as true firs (Abies spp.), do not even initiate root growth for at least a week under these environmental conditions.

5. Failure to recognize physiological differences between species. As mentioned in the previous section, different species have different root production patterns. Compared to Douglas-fir seedlings, ponderosa pine (Pinus ponderosa Dougl. ex Loud.) produce fewer, larger diameter roots, which would result in a lower RGP rating using Burdett's scale. Tinus and others (1986) studied RGP patterns for ponderosa pine, Douglas-fir and Engelmann spruce (Picea engelmannii Parry ex Engelm.) over 4 different environmental stages and found considerable species variation, particularly with ponderosa pine. Using a standard root evaluation scale for all species may lead to faulty conclusions about seedling quality - it may

be necessary to define specific standards for different species or groups of species.

The standard RGP test environment was designed around the optimum growing regime for commercially important tree species, such as coastal Douglas-fir. Different species, and even different ecotypes, grow different lengths and volumes of roots, over different time periods, and at different soil temperatures (Sutton 1980). For example, some true firs, such as noble fir (Abies procera Rehd.), cease root growth at approximately 18 ^{o}C (65^{o} F), even though common RGP test procedures use root mist chamber or water bath temperatures of 18 to 21 ^{o}C (65 to 70 ^{o}F). Based on these currently-used test environments, RGP results would be erroneously low for noble fir.

6. Overriding effect of outplanting site conditions. The environment on the outplanting site, particularly soil moisture, is crucial to seedling performance. Under extremely moist conditions, most seedlings will survive irrespective of their RGP ratings whereas under xeric conditions, few seedlings may survive. This "filtering effect" of environment is probably one of the most confounding factors in attempting to correlate seedling quality indices with outplanting survival. Burdett (1987) discusses this conundrum and emphasizes that RGP tests do not predict actual seedling survival, but only survival potential.

7. Defining the relationship between RGP and outplanting performance. One of the assumptions in using RGP tests to predict outplanting performance is that there is an identifiable mathematical relationship between the amount of roots that a seedling can produce under ideal conditions and how well that seedling performs after outplanting. Through the use of regression analysis, a prediction equation can be developed and used to estimate outplanting performance (the dependent variable), using RGP values (the independent variable).

This relationship is probably not a simple linear regression, however, and may involve more complicated statistical manipulations. The addition of other independent variables (multiple regression analysis) may help the precision of the prediction equation; perhaps inclusion of a variable to describe relative outplanting site conditions would be useful. Few relationships in nature can be predicted with one variable and it is naive to assume that outplanting performance is any different.

A more realistic possibility is that there may be a "threshold point" at which the mathematical relationship between RGP and outplanting survival changes form or becomes useless due to excessive variation. This threshold point hypothesis is both logical and useful. Regression analysis assumes that there is a continuous mathematical relationship between the amount of new roots that a seedling can produce and outplanting performance - few roots means poor suvival and growth and more roots means better performance. Actually, under given outplanting site conditions, there is probably some critical number or amount of roots necessary for initial survival: seedlings with fewer roots do not survive whereas seedlings with more roots not only survive but grow in proportion to the number of new roots. Dunsworth (1986) proposes a threshold RGP value of 1.0, using Burdett's scale, as "red light/green light" for determining whether a group of seedlings should be outplanted. An RGC threshold value (10 roots greater than 10 mm in length per seedling) has been proposed as a batch culling guideline for several northwest conifer species (Simpson and others 1988).

CONCLUSIONS AND RECOMMENDATIONS

1. Keep RGP and other seedling quality tests in perspective. There is no single answer for predicting seedling outplanting performance. Because of the complexity and interrelationships involved, we don't currently have, and probably never will have, a single test for measuring seedling quality. To continue with the tool analogy introduced earlier, it takes more than one type of tool to tune-up your car. Other quick, one-test measures of seedling quality, such as the "dormancy meter" (Jaramillo, 1981), have not proven to be operationally useful.

2. RGP is only one aspect of seedling quality, and should be considered in concert with other seedling quality information. Cold hardiness tests, because they are indicative of overall seedling stress resistance, may be more useful for predicting outplanting performance, especially if they include an associated test of seedling vitality. Dunsworth (1986) suggests that measures of stress resistance, such as cold hardiness and dormancy, may be good predictors of seedling survival. Ritchie (1985) proposes that RGP tests are actually reflecting stress resistance, which is more related to outplanting performance than "the ability to grow root per se".

3. The timing of seedling quality tests, including RGP, is important. For reforestation purposes, the best time to monitor seedling quality, including RGP, is as close to the outplanting period as possible because seedling quality can change significantly due to storage and handling. The next best sampling time would be just prior to shipment from the nursery. Seedling quality tests taken during seedling harvesting should be used to evaluate nursery performance rather than outplanting success.

4. It is traditional to conclude these technical papers with the observation that "more research is needed". One productive area of research would be to develop better root growth rating systems that can be adjusted for different species of seedlings. Future research may also clarify the relationship between RGP and

outplanting performance. Perhaps there is some magic formula that will mathematically describe this relationship and allow precise and accurate predictions, although it is doubtful. More likely, future research will reveal a "threshold" RGC rating, which varies with species, that will help to differentiate between good seedlots and ones that are critically weak.

5. This discussion should not be interpreted to infer that RGP tests are useless for predicting outplanting performance. On the contrary, RGP tests do provide some valuable information but, until we can better define the relationships involved, they should be interpreted primarily as a measure of seedling vitality, not relative vigor.

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Author's Note: This paper is the result of informal discussions with many different people, and much of this information is unpublished. Therefore, while we cannot cite their individual contributions, we would like to acknowledge them: W. Lopushinsky, D. Henneman, and D. Simpson.

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Root Growth Potential: Facts, Myths, Value?[1]

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Abstract.-- Currently the Root Growth Potential (RGP) test enjoys a reputation as a general predictor of outplanting survival and growth. This study examines the accuracy, precision and repeatability of RGP. We conclude that the present use of RGP is neither highly accurate, precise, or repeatable: within-test variation is highly variable; different test environments and durations give different results; mean batch RGP values from operational RGP tests do not display strong relations to outplanting mortality or growth. We conclude that RGP has value as part of a stock evaluation program but it must not be the sole arbiter. Any interpretation of RGP test results for predicting outplanting performance must consider other information on stock condition, history, and site conditions.

INTRODUCTION

Root growth potential (RGP) has been portrayed by research as a "thermometer" of seedling quality (Ritchie 1985) The operational use is being increasingly advocated and applied (Anon. 1988).

Recent reviews (Burdett 1987; Sutton 1988) have focused on the lack of an understanding of the physiological basis for RGP. Derived stock quality interpretations are ambiguous. We take the position that this ambiguous interpretation of RGP is due to a failure to: recognize latent assumptions; unrealistic expectations; failure to specify purpose; and lack of methodological understanding of RGP. Here we expand on this position examining these previously ignored issues. We propose revised interpretations of RGP for operational purposes that are consistent with the test methodology.

HISTORY AND ASSUMPTIONS OF RGP USE

Detailed reviews of the development and use of RGP have been published (Ritchie and Dunlap 1980; Ritchie 1985; Burdett 1987). It is important to distinguish the purpose, method, and interpretation of RGP. RGP testing was developed in response to poor field performance of conifer seedlings as a means of predicting operational outplanting performance (Stone 1955). In spite of numerous predictive claims made about RGP, the test is only a limited potting trial. RGP is simply a test of the potential to grow roots and says nothing about outplanting survival. Making an outplanting prediction is an interpretation of an RGP test.

Over the last 30 years RGP testing has been applied to virtually all conifer species and stocktypes as well as some hardwood species (Ritchie 1985; Burdett 1987). In British Columbia and many other places, RGP tests bear little resemblance to the 30-day greenhouse test of Stone and Jenkinson (1971). Present tests are conducted under much shorter test durations, elevated temperatures, prolonged day lengths, and controlled environments in a variety of media (Thompson and Timmis 1978). RGP is reported to be influenced by a variety of cultural practises (Ritchie and Dunlap 1980). Stocktype (Burdett et *al.* 1983), genotype and provenance (Nambiar et *al.* 1982), and dormancy state (Johnson-Flanagan and Owens 1985) have also been implicated.

Although the test conditions and materials have changed, the interpretations of the test have not. One has only to consider the changes in nursery culture and silvicultural practise of the last 30 years to question whether the original interpretations of RGP tests remain realistic without modification.

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[1] Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

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The operational appeal of RGP as a stock quality grading tool is based on the reported strong relation with outplanting performance (Fig. 1). The apparent simplicity and speed of the test (Day 1982) further enhances its attraction for operations.

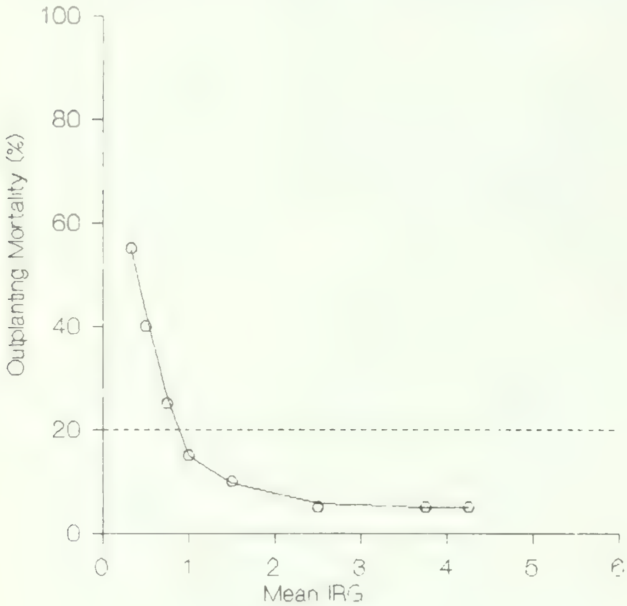

Figure 1.-- Relation between IRG and outplanting survival for bare-root lodgepole pine (after Burdett 1979, Figure 3). The horizontal line indicates an unacceptable mortality of 20%.

The fundamental assumption of RGP is quite reasonable:

> Individual seedlings exhibiting the largest number of new roots in an RGP test would have been better able to set new roots, survive, and grow in a plantation.

This assumption has led to the operational definition of the RGP test as:

> The number of roots initiated in a given interval of time under a favorable environment that are greater than 1 cm.

Numerous ways have been devised to test, express and interpret RGP (Ritchie 1985; Burdett 1987; Rietveld and Tinus 1987; Burr *et al.* 1987) but the basic methodological issues of accuracy, precision, and repeatability have not been explicitly considered. Like any measurement technique, RGP must be demonstrated to be accurate, precise, and repeatable before confidence can be placed in derived interpretations.

Before transferring this research technology to operational applications these methodological issues of accuracy, precision, and repeatability must be addressed.

ACCURACY, PRECISION, AND REPEATABILITY

Accuracy and precision are rigorously defined statistical concepts (Sokal and Rohlf 1969). Repeatability is the user-related component of accuracy and precision (i.e. observer error). These concepts are as important to the practise of statistics and conduct of laboratory technique as they are to target shooting (Fig. 2).

The accuracy, precision, and repeatability of a method determines the suitability for a specific purpose. Obviously one would wish any measurement technique to have high accuracy, precision, and give similar results regardless of who applies the test. However, useful methods may have poor precision but be accurate and repeatable enough to perform the required job.

The questions we are asking in this paper are:

1. Is RGP an accurate predictor of seedling vigor? (Can RGP correctly predict seedling survival?)
2. Is RGP a precise measurement of seedling vigor? (Is the variability of RGP measurements low?)
3. Is RGP a repeatable measurement? (Will several observers report the same result?)

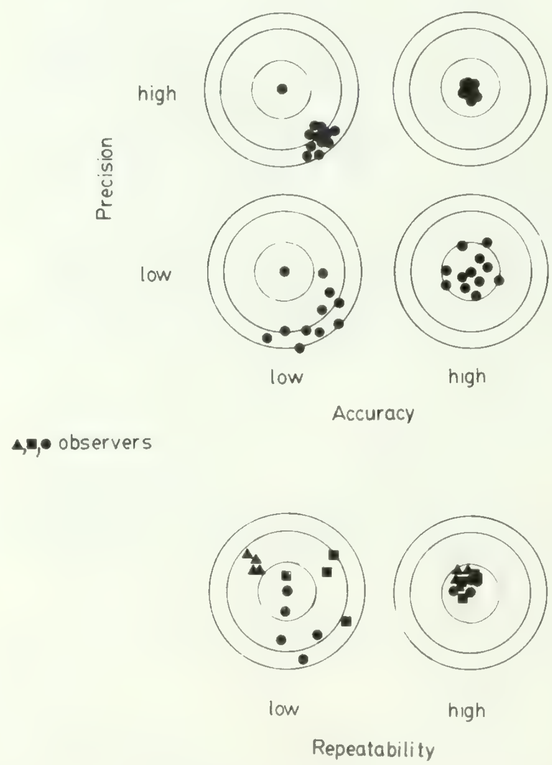

Figure 2.-- The sharpshooters analogy of accuracy, precision, and repeatability. The different shaped symbols represent different shooters.

TEST STABILITY

A common failure of RGP tests has been a lack of a standard test environment and duration. Thompson and Timmis (1978) reviewed the plethora of test environments used. New versions are published frequently (Burr *et al.* 1987; McCreary and Duryea 1987; Rietveld and Tinus 1987). Test environments have been described that are: sub-optimal, optimal, and too optimal. Among other factors, RGP has been shown to be influenced by test temperatures (Abod et al. 1979) and test media (Thompson and Timmis 1978). Without a clear understanding of the physiological basis of RGP, the choice of test environment and duration must be considered an arbitrary decision.

Figure 3 (Binder *et al.*, in prep.) illustrates test variability in two seedlots of western hemlock. The within-test variation is high. There are large differences between test temperatures with an optimal temperature less than the 30° day/25°night[5]. Longer test durations produced more roots. "Optimal" temperatures varied among seedlots of other species tested. These results indicate that conditions of Burdett's "quick test" (Burdett 1979; 30° day/25°night for 7 days) may be too warm and short for coastal species.

The IRG differences observed under different test temperatures suggests that extrapolation from laboratory test conditions to highly variable and fluctuating, sub-optimal plantations conditions may not be reasonable. Indeed, the modest 5C° diurnal variation encountered in laboratory growth chambers is physiologically trivial compared to the 30C° diurnal fluctuation seen in many operational plantations.

Others have commented on the large within-test variability (Stone et *al.* 1962; Stupendick and Shepherd 1979; Abod et *al.* 1979; Rietveld and Tinus 1987) and have made qualifying remarks concerning the <u>research</u> interpretations drawn. Although this variation has been commented on, it has not usually been graphically portrayed (i.e. Burdett 1979; McCreary and Duryea 1987) contributing to the impression of strong relation to outplanting mortality and growth.

The reported wide range of test conditions suggests poor repeatability between different studies. The large within-test variation results and observations suggest that RGP test results have poor precision.

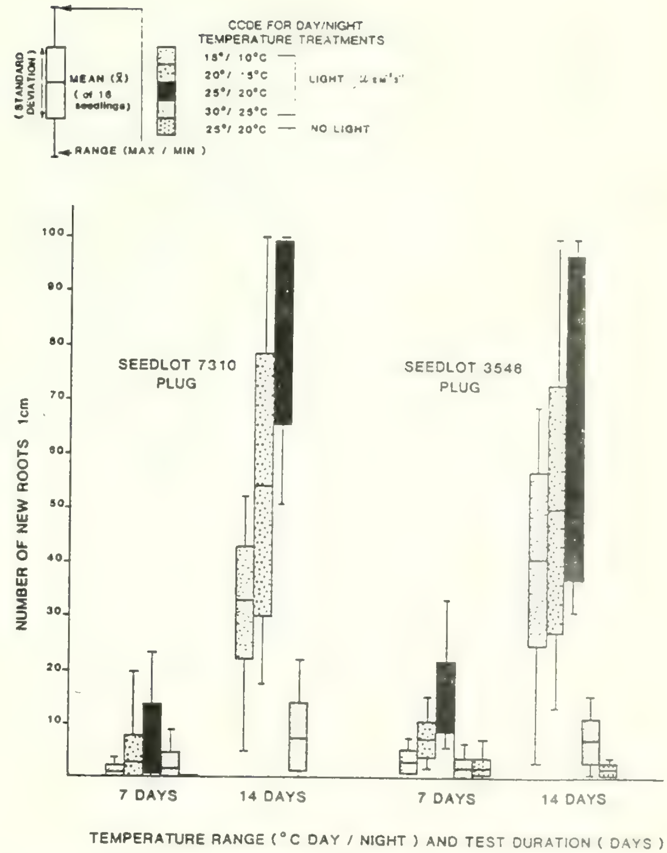

Figure 3.-- Comparison of the RGP for two seedlots of container-grown western hemlock tested under 5 test temperatures and two test durations (Binder et al., unpubl.).

NURSERY OUTPLANTING

Following Burdett et al. (1983) the British Columbia Ministry of Forests and Lands established an RGP monitoring program. Test temperatures and durations were standardized for all species (Binder, unpubl.) and nursery outplantings conducted at four nurseries. RGP tests were based on 16 seedlings. Nursery outplanting is based on plots of 50 seedlings. Twelve species and a wide diversity of stock types were examined.

The relation of IRG to nursery outplanting of 540 different batches is given in Figure 4. This figure represents 8,640 RGP tested seedlings and 27,000 seedlings in outplanting plots. No equation has been fitted through this point swarm as the large sample size makes it possible to claim statistical significance for any imaginable curve. Drawing such a line through the data gives credibility to a correlation that lacks general practical significance. The high within-test variation observed in Figure 3 also exists in this data. Including standard errors around the mean IRG values in Figure 4 would reinforce the impression of randomness.

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[5] Unless otherwise specified all RGP tests were performed at 25C° 16 hour day of 400 $uEm^{-2}sec^{-1}$ provided by fluorescent and incandescent lamps. The 8-hour night temperature was 20C°. Tests were run for 7 days. Relative humidity of the growth chambers was 75%±5%. Tests consisted of 16 seedlings potted four to a 6" pot of 3:1 peat vermiculite adjusted to pH 5.0 with dolomite lime.

The good news contained in Figure 4 is that only 12% of the seedlots tested had an unacceptable mortality of greater than 20%. The majority of mortality occurred within the first year of the outplanting, often within weeks of planting. One would have predicted a similar small percentage of batches would have had very low IRG. However 45% of the seedlots tested had an IRG of less than 2. There were many instances where very poor IRG resulted in very good survival and *vice versa*.

The nursery outplanting results question the predictive abilities of RGP and suggest poor accuracy. The high within-test variation suggests poor precision. Reported differences in testing procedures (Heywood-Farmer, pers comm.) and variation between observers conducting the test (Scagel, unpubl.) suggest poor repeatability.

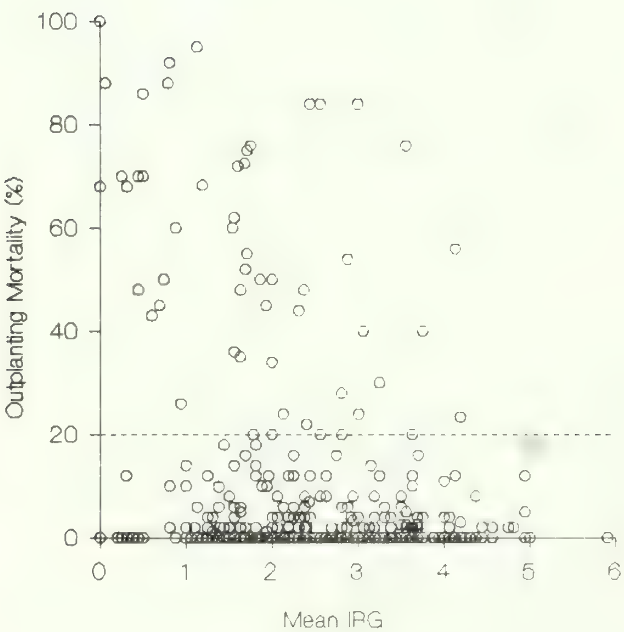

Figure 4.-- Operational IRG related to two-year nursery outplanting mortality for 540 batches of seedlings. The data includes 12 species and numerous stocktypes tested over two years by the BC Ministry of Forests Nurseries. The horizontal line indicates an unacceptable mortality of 20%. Figure 7 expresses this figure to yield interpretations of IRG given in Table 1.

CONTROLLED IRRIGATION OUTPLANTING

Although nursery outplanting plots are neither irrigated or fertilized, it has been argued that these environments are not extreme enough to indicate differential RGP-related mortality. Burdett (1987) attributes the hypothesis of site-specific RGP-related mortality to Stone (1955). That is, only stock with high RGP is capable of surviving on harsh sites, while low RGP stock can only survive on less extreme sites.

Scagel *et al.* (in prep.) examined this hypothesis in an irrigated farm field trial modeled on the work of Blake *et al.* (1979). Three irrigation regimes were used:

- dry - no irrigation
- fresh - irrigated every second week
- moist - irrigated every week

Three stocktypes of the same seedlot of coastal Douglas-fir grown at a single nursery were used. Several liftings of seedlings were made in expectation of realizing a wide of IRGs (Figure 5). A wide range of IRGs were obtained.

Figure 5 illustrates the two-year outplanting mortality for each of the irrigation regimes. The within-test variation was similar to that presented in Figure 3. There was no consistent ranking of stocktype-liftdate mortality over the three irrigation regimes. Longer storage was associated with a decreased IRG but was of no consequence to general survival. As observed in the nursery outplanting plots, most death occurred within the first year - most death within weeks of planting.

The only suggestion of a relation between outplanting mortality and IRG occurred on the dry site. On the dry site all stocktypes and lift dates had unacceptable mortality. Unacceptable mortality also occurred on the other two sites. There were no IRG-related relative growth differences but there were large site-related growth and form differences.

The physiological impediments to seedling survival and performance imposed by the plantation environment are critical considerations in stocktype selection and stock quality evaluation. Quality is fitness for purpose (Sutton 1980). These results suggest RGP offers only limited prediction of seedling survival. These predictions might be applicable to extreme environments but the within-test variation mediates against such strict interpretation. Although RGP may have some accuracy, the precision is low.

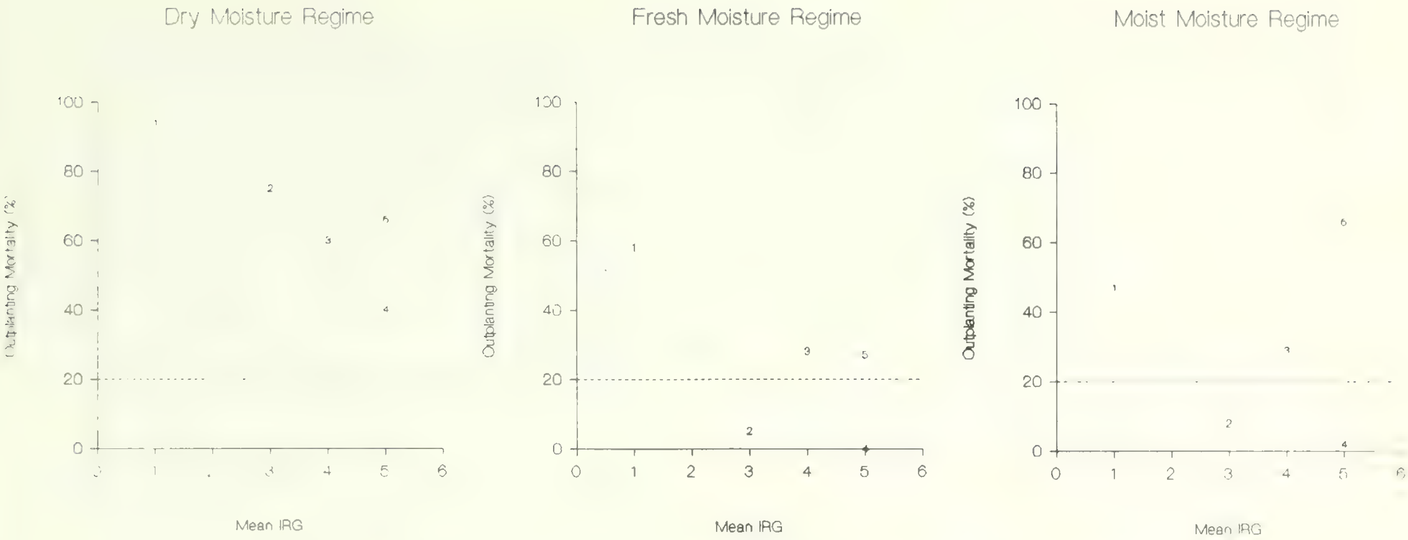

Figure 5.-- Mean IRG of various liftdates and stocktypes of Douglas-fir related to two-year mortality in three controlled environments. The horizontal line indicates an unacceptable mortality of 20%. 1, January-lifted plug-transplant; 2, January-lifted 2+0 bareroot; 3, December-lifted PSB 313; 4, January-lifted PSB 313; 5, February-lifted PSB 313.

OPERATIONAL OUTPLANTING

The acid-test of the utility of RGP as a stocky quality grading tool is not how well the test predicts outplanting mortality under carefully controlled research trials. The utility of the test is determined under operational plantation conditions.

Scagel *et al.* (in prep.) followed three seedlots of coastal Douglas-fir over a range of operational plantation environments on southern Vancouver Island. The sites studied were all suitable for Douglas-fir. The seedlots followed had very similar, high IRGs. According to the RGP test interpretation, these seedlots would be expected to have low mortalities.

The two-year outplanting mortality is given in Figure 6. The within-test variation was similar to that shown in Figure 3. Half of the plantations had an unacceptable mortality but there was little mortality observed in the nursery outplanting trials. As observed in nursery outplanting plots and irrigated field conditions, most mortality occurred within the first year - usually within weeks of planting. Excavation of dead and poorly growing seedlings indicated that microsite selection and site preparation were the primary factors determining mortality. Unlike mortality, growth correlated with plantation ecosystem. Inspection of planting reports indicated that there had also been delayed planting with attendant stock handling problems.

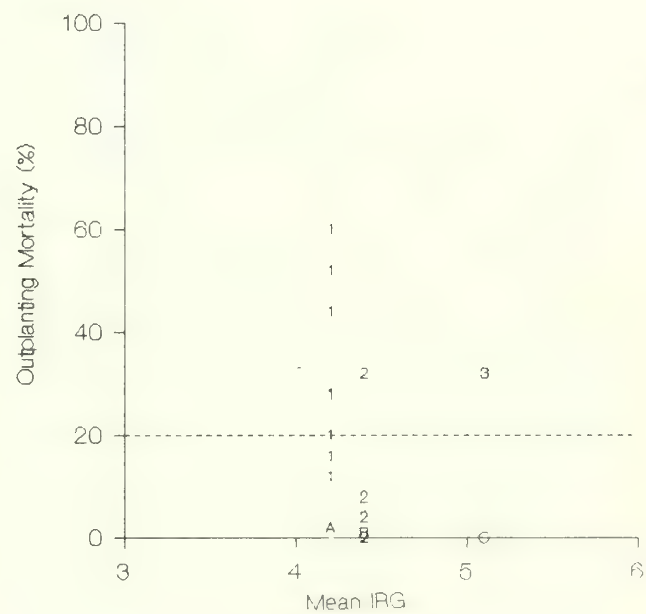

Figure 6.-- Mean IRG of three Douglas-fir seedlots related to two-year operational outplanting mortality in commercial plantations and nursery outplanting plots. The horizontal line indicates an unacceptable mortality of 20%. 1, 2+0 bareroot; A, nursery outplanting mortality of 1; 2, 2+0 bareroot; B, nursery outplanting mortality of 2; 3, 1+0 PSB 313; C, nursery outplanting mortality of 3.

These observations suggest that RGP differences can be equalized by stock handling and planting. This conclusion should not be surprising as there is no substitute for careful handling and storage, good planting, microsite selection, and microsite preparation.

These results iterate Landis and Skakel's (1988) comments about RGP being only a point estimate of stock quality. That is, the results of an RGP test are felt to be representative for the population at the time the sample was drawn and the test run. A lot of stock handling problems can occur in the two weeks it takes to run an RGP potting trial (Edgren 1984). Operationally, any predictive ability of an RGP test can be very quickly altered by poor handling practises.

The same conclusions about accuracy and precision are also clear: RGP appears to have poor accuracy and precision. In addition it may not be fast enough for operational silvicultural purposes. The lack of precision and accuracy under operational conditions suggests the test lacks <u>general</u> utility - although this does not mean that the test lacks <u>specific</u>, or special purpose, utility such as for research.

RGP USE

A planted, poor quality seedling can cost triple a mistakenly destroyed acceptable seedling. The silviculture cost increases even more if the costs are considered interest-bearing and the plantation requires replanting. RGP-mediated culling decisions should respect this economic consideration and strive to reject unacceptable seedlings.

"Seedling quality" is hard to define, difficult to quantify and impossible to make error-free culling decisions. There will always be instances where some of the good is thrown out with the bad and vice versa (Figure 7). This does not mean that seedling quality is not worth investigating. To minimize the acceptance of otherwise low vigor seedlings, both purpose <u>and</u> fitness must be stated.

RGP has value as <u>part</u> of a stock evaluation program but on its own offers only circumstantial evidence about seedling quality. RGP <u>can</u> suggest that seedling quality <u>may be</u> poor, but cannot provide explanations, solutions, or predictions of field performance. Other sources of information about the stock <u>and</u> the environment of the planting site are required before a stock quality judgement can be made.

In our experience, RGP tests have proved valuable when stock had been suspected of being poor quality as a result of other information on cultural or storage conditions. In these instances additional information on stock quality was critical in flagging suspect batches, repeated potting trials of large number of seedlings corroborated the suspicion, and additional information provided explanations for poor seedling quality.

Like a traffic light, we propose three general decision-making procedures be considered in interpreting the results of an RGP test (Table 1): reject, reserve, caution. These procedures reflect our position that RGP may have value only where extreme values are reported. Figure 7 emphasizes the chances of accepting poor quality batches. There is always a chance of accepting poor vigor stock - 10% of the high IRG batches had an unacceptable mortality.

Regardless of the test results.the test conditions and variability within the test should always be considered. We recommend that other sources of information about stock should be routinely considered even though they are indicated in Table 1 as optional. Many physiological and morphological tests have been devised and can be used (Duryea 1985). Knowing the cultural and storage history of the stock is the most important. As well, the plantation environment and the expected physiological impediments to plantation establishment in these environments must be considered.

Returning to the sharpshooters' analogy (Fig. 2), RGP is like a small caliber shotgun <u>not</u> a target pistol. It should be used accordingly.

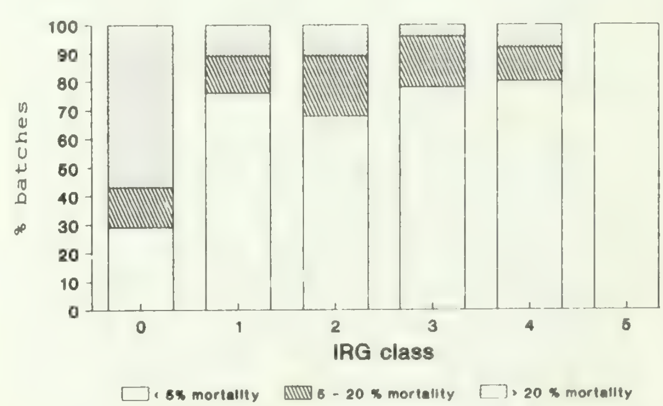

Figure 7.-- IRG interpretation for silvicultural risk. Figure 4 re-expressed to indicate mortality of a mean batch IRG. Mortality is based on nursery outplanting results.

Table 1 -- Decision making recommendations concerning RGP test results. Data are based on 540 operational RGP tests and nursery outplanting plot results. These results pool all species and stocktypes.

	RGP Interpretation Status		
	Red	Yellow	Green
Decision	Automatic rejection	Reserve decision Consider other info	Caution
Parameters			
mean IRG[1]	0	<2	>2
Chance of accepting an unacceptable batch[2] See Figure 7.	<1%	50%	10%
Additional stock information requirement	Not usually required	Required	Maybe
Type of information			
Test conditions	+	+	+
Purpose	(+)	+	(+)
Pathology	(+)	+	(+)
Morphology	(+)	+	(+)
Physiology	(+)	+	(+)
Storage history	(+)	+	(+)
Cultural history	(+)	+	(+)

[1] IRG from Burdett (1979).
[2] "unacceptable" is considered greater than 20% mortality in a nursery outplanting plot. Actual plantation conditions could require adjusting IRG limits.
+ collect other information; (+) other information optional.

SUMMARY

Under present operational testing regimes the accuracy, precision, and repeatability of RGP is low enough that stock quality assessments performed solely on RGP are suspect. An RGP test does not absolve the forester or nurseryman from the responsibility of looking closer at the seedlings that are being purchased - particularly during their nursery tenure. Combinations of methods as well as cultural and silvicultural considerations must be used in decision-making processes concerning stock quality.

Owing to the inconsistency and variability of RGP test results, one must question whether predicating the utility of other methods of assessing stock quality on a comparison to RGP is appropriate. We also question the appropriateness of transferring research technology with these limitations to a fully operational stock evaluation program.

These conclusions are not surprising as seedlings are sensitive to temperature, moisture, nutrients, and aeration. This sensitivity is exploited daily in a nursery environment. How seedlings respond to their environment is a function of their cultural history and current developmental state. Rigorous stock evaluation must consider the dynamic and interdependent nature of biological systems. To assume otherwise is to consider seedlings little more than widgets.

ACKNOWLEDGMENTS

This project is funded under the Canada British Columbia Joint Forest Resource Development Agreement (FRDA 2.02). We would like to thank the many nurserymen and field silviculturalists who have gone out of their way to discuss these ideas with us and in particular Ev van Eerden.

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Root Growth Capacity Effects on Field Performance[1]

David G. Simpson, Alan Vyse, and C.F. Thompson[2]

Abstract.--Good field performance (first year survival) was found for interior spruce (Picea glauca x engelmannii) or lodgepole pine (Pinus contorta) seedlots that had average root growth capacity (RGC) levels greater than 10 new roots longer than 10 mm per seedling. The RGC-field survival relationship was affected by both species and planting year, but not so much by planting site.

INTRODUCTION

Since 1977 forest nurseries in British Columbia have routinely determined the root growth capacity (RGC) of batches of nursery stock. The method used is similar to that described by Burdett (1979). For the major species planted in British Columbia, correlations between RGC and field performance (survival and/or growth) are often found (Burdett et al. 1983; van den Driessche 1983; Simpson unpubl.).

Beyond merely assuming that a higher level of RGC is better than a lower level, interpretation of RGC test results has been difficult. A number of factors act to confound interpretation including: sampling problems, large tree-to-tree variation, suitability of test duration and conditions, uncontrolled or unknown variations in other physiological and morphological characteristics which may affect field performance, and interactions with planting site environment.

The purpose of this experiment was to determine the nature of the relationship between RGC and field performance for interior spruce (Picea glauca x engelmannii), lodgepole pine (Pinus contorta) and interior Douglas-fir (Pseudotsuga menziesii var. glauca) on a range of ecologically different forest planting sites in British Columbia's southern interior.

THE EXPERIMENT

To establish relationships between RGC and field performance, it is necessary that batches of stock ranging in RGC from none to many roots per plant are available and that these batches of stock are planted at the same time and on the same planting site.

In this experiment, batches of stock with a wide range of RGC were obtained from cold storage after reviewing the BC Ministry of Forests' RGC testing results. For each species (interior spruce, lodgepole pine, and Douglas-fir) 20 to 30 batches of stock (seedlots) were identified and shipped to the Kalamalka Research Station near Vernon, B.C. The stock was re-packaged and RGC re-measured shortly prior to establishment of outplantings.

The RGC testing procedures were similar to those described by Burdett (1979). Seedlings were potted in 3:1 peat-vermiculite soil mix and grown for 7 days in conditions providing 18-hour days (400 $\mu mol/m^2/s$), 30°C-day and 25°C-night temperatures. The root growth assessment procedures differed only in that the total number of newly elongated roots longer than 10 mm on each seedling was recorded.

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[1]Presented at the Western Forest Nursery Council - Forest Nursery Association of BC meeting, August 9-11, 1988, Vernon, B.C. Canada.

[2]The authors are research scientists with the B.C. Ministry of Forests at Vernon, Kamloops, and Nelson, B.C., respectively.

Between 1985 and 1987, 18 plantations were established on a range of forest site types in British Columbia's southern interior (table 1). Each outplanting consisted of three blocks with 20 to 30 rows of 25 seedlings. The order of rows was randomized within each block.

Table 1.--Outplanting sites

	Site Type[1]	Planting year
Interior spruce	ICHe2	1985
	ICHm1	1986
	ESSFm	1986
	ESSFd4	1986
	MSB1	1987
	ESSF	1987
	ESSFm	1987
Lodgepole pine	ICHm1	1986
	ESSFd4	1986
	ICHm2	1987
	ICHa1	1987
Douglas-fir	IDFb	1986
	IDFb	1986
	ICHm2	1986
	IDFb	1987
	IDFb	1987
	ICHe2	1987
	ICHa1	1987

[1]Site types as described by the biogeoclimatic system used by the B.C. Ministry of Forests.

RESULTS AND DISCUSSION

In most cases the relationship between RGC and first year field survival for interior spruce and lodgepole pine but not interior Douglas-fir was asymptotic in shape (for example, fig. 1). Regression lines could be drawn through these scatter of points to indicate the proportion of survival variation that is a function of variation in RGC. While these type of curves are useful to show the nature of the relationship between RGC and field survival, they are not as useful for interpreting RGC data or more simply for determining an acceptable level of RGC for batch culling.

A more useful approach may be to consider various RGC threshold levels and then to examine the field survival of batches above and below those thresholds. The data in figure 1 suggest for those plantations a natural threshold exists at around a RGC level of 10 roots per plant.

When a threshold of 10 roots greater than 10 mm per plant is applied to the data obtained in this experiment (figure 2) the following observations can be made:

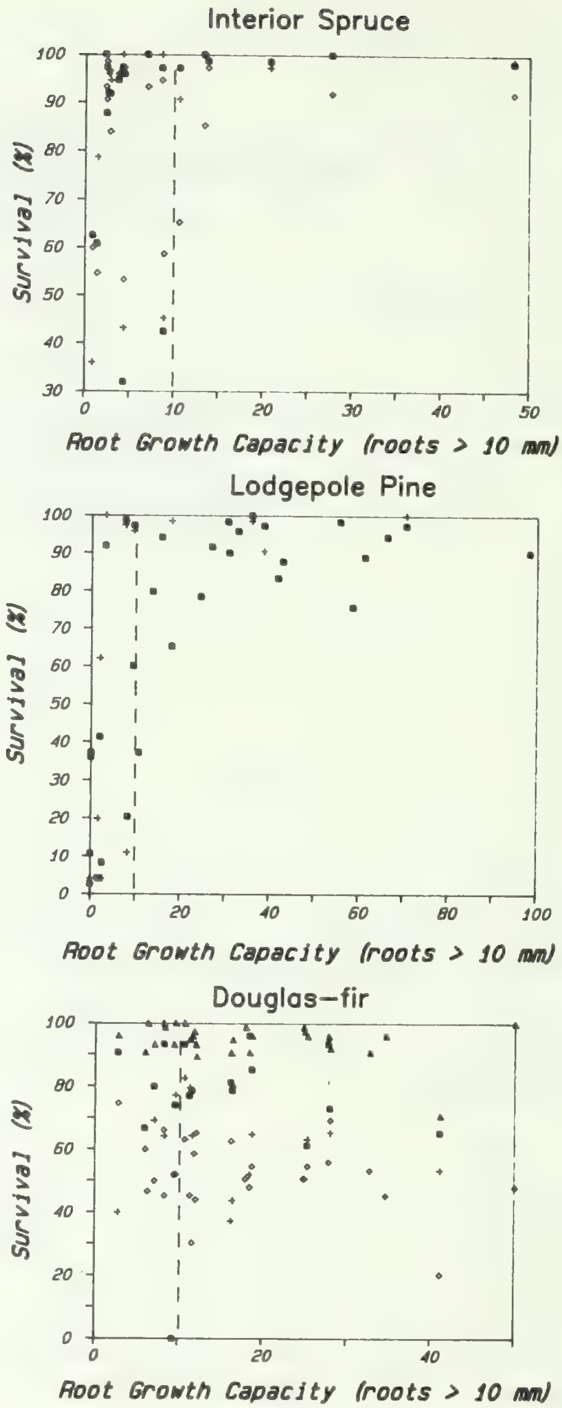

Figure 1.--First year field survival (%) of interior spruce, lodgepole pine, and Douglas-fir seedlings planted in 1986. Each point represents the mean RGC of a 20-seedling sample and the mean field survival of 75 seedlings.

1. planting batches of stock with RGC levels greater than an average 10 roots per plant results in generally higher survival with less variation or chance of poor survival.

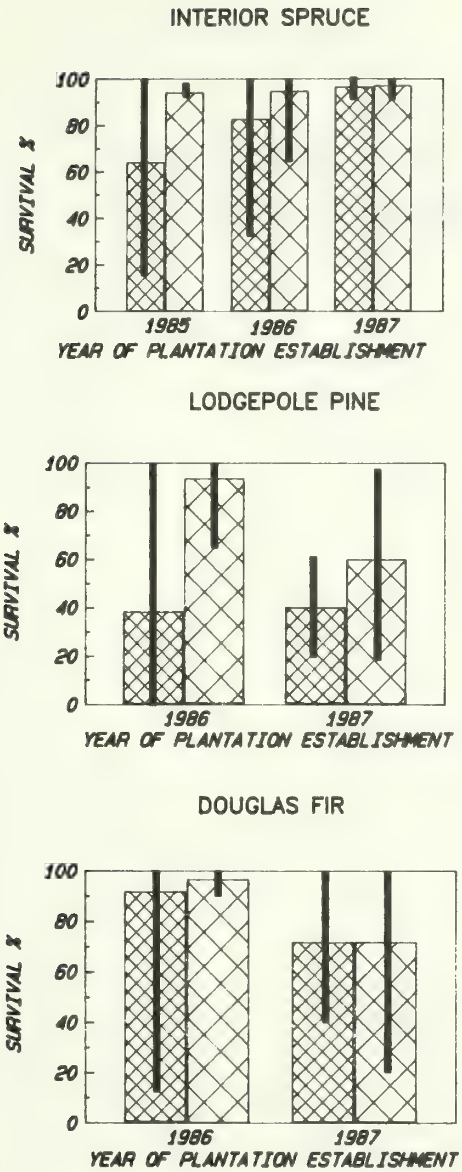

Figure 2.--First year field survival (%) of interior spruce, lodgepole pine, and Douglas-fir planted between 1985 and 1987. Bars represent mean RGC for seedlots with RGC's less than 10 roots per plant (narrow cross hatch) and greater than 10 roots per plant (wide cross hatch). Range of seedlot means is indicated.

2. there is an interaction with planting season; in some years RGC is not of predictive value in determining field performance.

3. there is a species interaction wherein the relationship between RGC and survival for both interior spruce and lodgepole pine seems similar, but there seems to be no relationship in Douglas-fir between RGC and survival. It is unclear why no relationship between RGC and Douglas-fir survival was found.

4. The RGC-survival relationships, at least for the first year, are little affected by planting site.

CONCLUSION

The data presented here suggest a natural RGC threshold of an average 10 roots per plant greater than 10 mm in length could be used as a batch culling guideline to ensure higher survival and less chance of plantation failure for interior spruce and lodgepole pine planted in British Columbia's southern interior. Barring unusual circumstances, seedlots whose RGC levels are greater than an average 10 roots per plant will survive very well on outplanting.

Due to the large survival variation in seedlots planted with RGC levels less than 10 roots per plant, it is expected that such a threshold, or batch cull level, if implemented in practice will result in destruction of some batches of stock which might in some circumstances have adequate field performance. The cost-benefit of batch culling based on low RGC levels should therefore be considered very carefully by forest managers before embarking on such a program.

Rather than using a batch culling program based on RGC (or some other aspect of stock quality), it would be more constructive to manipulate nursery cultural, cold storage, and stock handling practices to ensure that no batches of stock have RGC levels less than 10 roots per plant.

The results presented also support the need for further investigation of other stock quality measures to augment the widespread use of RGC testing.

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The Effects of Elevated Post-Storage Temperatures on the Physiology and Survival of White Spruce Seedlings[1]

W.D. Binder[2] and P. Fielder[3]

Abstract.--The objectives of this study were to determine the effects of elevated temperature and exposure time on the physiology and survival of post-cold stored white spruce (*Picea glauca* (Moench) Voss.) seedlings, and whether such effects could be detected quickly physiologically prior to planting. Foliage and root temperatures lagged behind ambient temperatures after transfer from storage (-2°C), to thawing (5°C), and from thawing to heat treatments (10, 20, 30, 40°C). Although no visible seedling damage was apparent after 12 h at 40°C, damage was 32% after 24 h. Seedling mortality was 48% after 48 h, and reached 100% after 72 h. At 30, 20 and 10°C no seedling mortality was observed for 24, 72 and 96 h respectively. Root Growth Capacity was poor in treated seedlings showing poor survival after planting. Seedling mortality of over 10% from elevated temperatures may be detected in about 24 h from specific conductivity of tissue leachates. This test, however, does not predict significant non-lethal heat stress tissue damage of seedlings prior to planting. Exposure of seedlings in boxes to temperatures above 10°C is not recommended.

INTRODUCTION

Survival of conifer seedlings after planting depends on their physiological state prior to storage, at the time of planting, and upon planting site conditions (Ritchie 1984; Duryea 1985). After lifting seedlings may be culled, counted, stored, loaded in and out of transporters, temporarily stored in the field and finally planted (Trewin 1978). During these operations seedlings may be exposed to a range of stresses including drying or freezing, mechanical damage to shoots and roots through impact (Trewin 1978; Tabbush 1986), and heating (DeYoe et al. 1986).

Exposure of conifer seedlings to heat may have a number of effects on seedling physiology and subsequent survival including stress metabolism (Haard 1983), excessive expenditure of food reserves (Mattsson 1986; Ritchie 1984; Puttonen 1980, 1986), and loss of cold hardiness (Levitt 1980). Stress due to heat increases with temperature and duration of exposure (Levitt 1980).

Although extreme heat results in rapid, extensive tissue death, the effects of more moderate heat stress on seedling vigour are not always visible and are usually only manifested after the stock has been planted (Kauppi 1984). Determining seedlings vigour status using potting trials often takes too long for the nurseryperson to make a decision about stock quality before shipment to the planting site. However, some physiological attributes may be detected which reveal relationships between stock quality and subsequent survival after planting (Wakely 1948; Zaerr 1985).

This study reports: i) the amount of heat stress which can be applied to white spruce seedlings after cold storage without a decrease in survival or vigour, ii) and whether the results of heat stress can be detected by physiological tests prior to planting. Results indicate the tolerance of the test seedlot to heat stress during thawing, pre-shipment storage, transportation, or storage at the planting site.

[1] This paper was presented as a poster at the Combined Western Forestry Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association Meeting; 1988 August 8-11; Vernon, British Columbia.

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METHODS OF INVESTIGATION

General

White spruce 1-0, PB313 styroblock containerized seedlings (seedlot Sw, 8504, 87G09005), destined for spring planting in north-eastern British Columbia, were grown under operational conditions at a nursery near Vancouver, British Columbia in 1987. Seedlings were lifted in late November 1987 and cold stored (-2°C) at the Ministry of Forests, Research Laboratory, Glyn Road, Victoria, B.C.

Waxed cardboard boxes (36x14 in.) were lined with a wax paper bag and seedlings were packed, 500 to a box in bundles of 20 with plugs wrapped in plastic. Boxes were then sealed with tape so that they could be reopened to remove samples.

In the spring of 1988 physiological measurements were made during two time intervals because of the short sampling period and available growth chamber space. Each period included an 8-day thaw at 5°C followed by up to 96 h heat. The first sample period began on April 11, 1988 and the second on April 26.

Samples were taken of frozen seedlings, and seedlings which had been thawed for 8 days. Following the thaw period seedlings were placed into the randomly assigned temperature treatments, 5, 10 and 40°C during the first experimental period and 20 and 30°C during the second. Seedlings were sampled and measured after 12, 24, 48, 72, 96 h.

The temperature inside boxes was recorded constantly throughout the experiment with thermistors monitored by a Campbell CR10 datalogger. Each box contained three temperature probes measuring foliage, and root temperatures of inner and outermost seedling bundles.

Each temperature treatment was represented by only one growth chamber because of limited equipment availability.

Specific Conductivity of Leachates

The amount of electrolyte leakage from tissues is a relative measure of the degree of cell membrane damage caused by exposure of seedlings to stress (i.e. low or high temperatures). The method used here is modified from van den Driessche (1976) and Burr et al. (1986).

Measurements were made after 24, 48, 72 and 96 h. Fifteen seedlings were divided at random into three replicates of five seedlings. The middle 8 cm section of stem of each seedling was cut into 15, 0.5 cm stem segments. Three segments were randomly selected from each of the five seedlings and placed in a covered test tube.

Needle segments 1 cm long, cut at both ends, were taken from one side of the stem of each seedling. All needles removed from one seedling were mixed and subsamples of needles from each of five trees in each replicate combined to give an approximate final weight of 0.7 g.

During preparation the stem and needle segments were kept in small plastic petri dishes on moist filter paper before transferring them to test tubes. Deionised water was added to the tissue segments in a ratio of 10:1 by weight. The specific conductance of the leachates were determined with a Radiometer CDM83 Conductivity meter after 24 h in a water bath at 25°C.

Root Growth Capacity

Root Growth Capacity (RGC) tests were conducted on 16 seedlings removed; i) directly from cold storage ii) at time zero of the treatment period (end of thaw) and, iii) after 48 and 96 h. For the 20 and 30°C heat treatments testswere also conducted after 24 h. Test conditions were carried out according to B.C. Ministry of Forests standards for white spruce, (400 μ mol^{-2}.s^{-1}, 30°C day/25°C night, 75%RH and a 16 h light period. Pots, containing a peat/vermiculite mixture (pH 5.7) were watered to field capacity at time zero and after 5 days. After a test period of 7 days the numbers of roots >1 cm produced during the test were counted and the Index of Root Growth calculated (IRG) (Burdett 1979).

Survival of Heat Treated Seedlings

Immediately after treatment seedlings were planted on site at the Glyn road Research Laboratory. Seedlings were planted in a completely randomized design. No water or fertilizer was applied.

Seedlings were evaluated for mortality and damage two months after planting. A seedling was considered dead if needle damage extended over the whole shoot. Damage (between 10 and 90%) to each seedling was scored as a percentage of the total plot sample (50 seedlings) if the seedling was not dead.

RESULTS AND DISCUSSION

Temperature inside boxes did not immediately reach target levels (Figs. 1 and 2). This lag time, may account for the surprising tolerance of this seedlot at the highest heat treatment. The 40°C treatment temperature was not reached until almost 20 h after treatment started, but was about 36°C within 6 h (Fig. 1) and over 30°C within 3 h. There can also be a differential heating rate up to 8 h between outer and inner bundles in an box (compare Fig. 1 to Fig. 2).

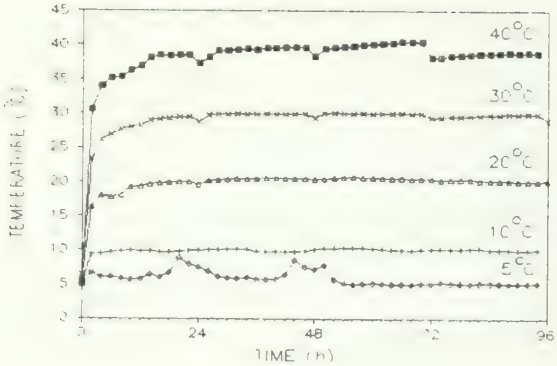

Figure 1. Foliage temperatures (°C) inside boxes during both experimental treatment periods, from April 18-22 (40, 10, and 5°C) and May 02-06 (20 and 30°C).

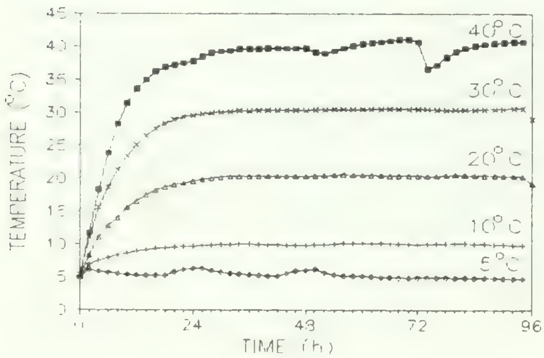

Figure 2. Root temperatures (°C) inside boxes during both experimental periods, from April 18-22 (40, 10 and 5°C) and May 02-06 (20 and 30°C). A bundle from the centre of the box was monitored.

Survival

Table 1 shows the percentage of damage (D) and mortality (M) of treated seedlings 2 months after planting on a moist site. Mortality was <4% and there was no damage to live seedlings which were planted after removal from cold storage (-2°C), and after thawing at 5°C for 8 days. After 96 h at 5, 10 and 20°C mortality was <10% and damage was zero.

Mortality and damage increased with length of treatment at 30 and 40°C. At 30°C mortality was <10% up to 48 h but increased to 18 and 40% at 72 and 96 h. At 40°C visible damage was observed at 24 h and mortality was 48% by 48 h and 100% by 72 h.

Root Growth Capacity

Figure 3 shows that the Index of Root Growth (IRG) was acceptable by operational standards over the thawing period and there was no significant change over the treatment period at 5, 10 and 20°C. At the start of the heat treatments IRG was about 3.5, after 48 h at the 30 and 40°C treatments IRG had decreased to 2.5 and to 0.2 respectively. Only a slight decrease in IRG was noted in seedlings which received 20°C for 96 h, but IRG decreased to 0.5 at 30°C and was zero at 40°C.

Table I. Percentage of field mortality (M) and damage (D) to white spruce seedlings resulting from heating for up to 96 h. Dashes indicate damage or mortality was <4%.

TEMP (°C)		DURATION OF TREATMENT (H) 0		12		24		48		72		96	
		M	D	M	D	M	D	M	D	M	D	M	D
THAW	5	-	-	-	-	-	-	-	-	-	-	-	-
HEAT	5	-	-	-	-	-	-	-	-	-	-	6	-
	10	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	8	-	6	-
	30	-	-	-	-	6	16	4	-	18	16	40	20
	40	-	-	-	-	4	32	48	4	100	--	100	--

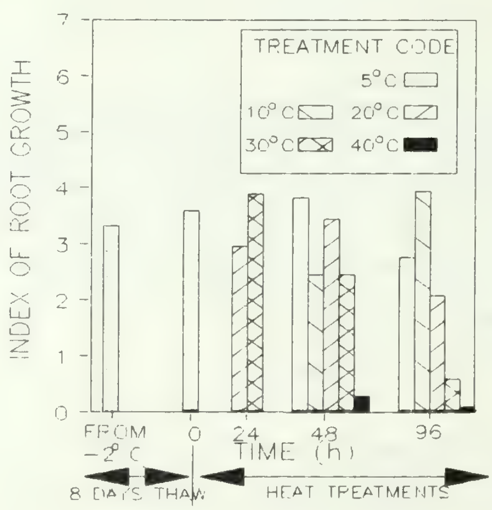

Figure 3. Index of Root Growth (IRG) of white spruce seedlings after treatment at five storage temperatures (5, 10, 20, 30 and 40°C) for up to 96 h.

Figures 4, 5 and 6 show roots on seedlings at 10°C and 30°C for 96 h and 40°C for 48 h. Seedlings in the latter two temperature treatments had visible shoot damage compared with those which were held at 10°C for 96 h. A comparison of Table I and Figure 3 indicates that IRG data seem to reflect quite well the field survival results.

Figure 4. Root development after an RGC test of seedlings previously treated to a 10°C storage temperature for 96 h. There was no visible damage to stems or needles. Buds were flushing.

Figure 5. Root development after an RGC test of seedlings previously treated to a 30°C storage temperature for 96 h. Considerable discolouration of stems and needles was noted in some seedlings. Buds were not flushing.

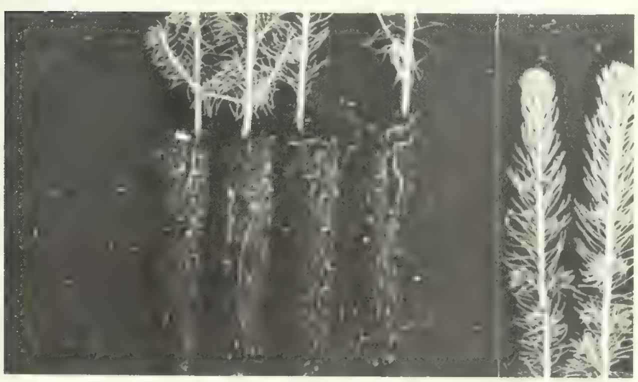

Figure 6. Root development after an RGC test of seedlings previously treated to a 40°C storage temperature for 48 h. Discolouration in many stems and needles was severe. Buds were not flushing.

Specific Conductivity

Specific conductivity of leachates from stem segments increased with length of treatment and temperature (Fig. 7). At 40°C specific conductivity increased after 48 h indicating cell damage (Fig. 7). At 20 and 30°C cell damage occured after 72 h treatment. (Actual temperatures inside boxes are shown in Figures 1 and 2).

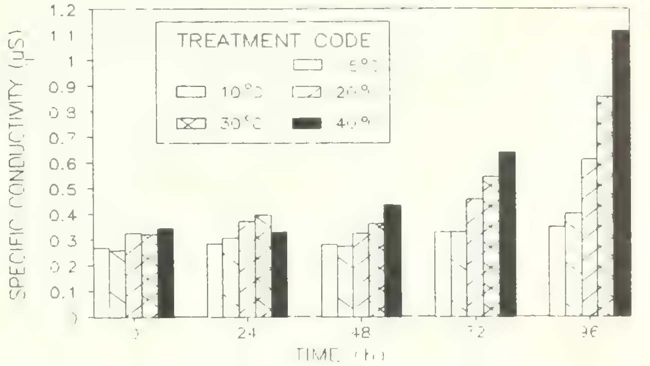

Figure 7. Specific conductivity (uS) of leachates from stem segments of white spruce after holding intact seedlings in five treatment temperatures up to 96 h. Segments were soaked in 10 times their fresh wt. (g) of deionised water for 24 h.

Specific conductivity of leachates from needle segments (Fig. 8) increased in 30 and 40°C treatments indicating tissue damage after 72 h. At 20°C an effect, although slight, was also noted after 72 h. However, this did not increase further after 96 h. At 5 and 10°C no change occurred up to 96 h.

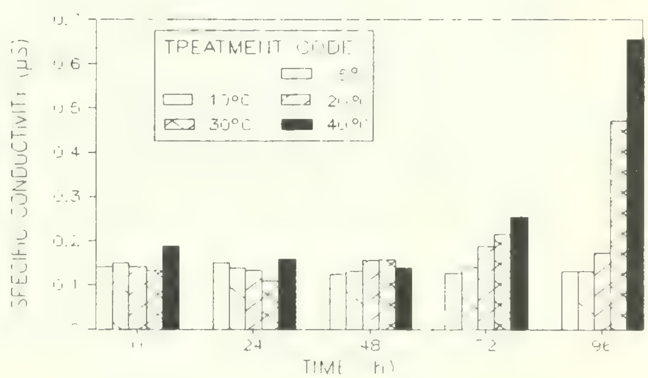

Figure 8. Specific conductivity (uS) of leachates from white spruce needle segments after holding intact seedlings in five treatment temperatures for up to 96 h. Segments were leached into 10 times their fresh wt.(g) of deionised water for 24 h.

Measurement of leachate conductivity from tissues may be useful to assess stock quality quickly (24 h) after damage from excessive heating. Conductivity has been used to assess other types of physiological stress e.g. frost damage (Colombo *et al.* 1984) for some time. However, the test at present seems to lack sensitivity. Below 48 h heat treatments did not result in a detectable increase in leachate conductivity (Figs. 7 and 8) despite significant visible seedling damage after outplanting (see 30°C after 24 h, Table 1). Results indicate mortality of greater than 10% is detectable. However, the amount of leachate detected increases with time within a specific treatment temperature and continues to increase even after mortality has reached 100% (c.f. Table 1 and Figures 7 and 8 at 40°C at 72 and 96 h). Measurement of leachates from stem segments appears to be a more sensitive indicator of heat damage than from needle segments.

ACKNOWLEDGEMENTS

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Variable Chlorophyll$_a$ Fluorescence and its Potential Use in Tree Seedling Production and Forest Regeneration[1]

W. Vidaver,[2] P. Toivonen,[3] G. Lister,[4] R. Brooke,[5] and W. Binder[6]

Abstract.--An integrating fluorometer for detection of variable chlorophyll$_a$ fluorescence has proven useful in determining the physiological status of conifer seedlings. Information obtained can be used in selecting lifting dates, in evaluating post-storage vigor and in assessing the effectiveness of nursery watering and fertilizer regimes.

INTRODUCTION

Radiation incident on a seedling canopy or leaf can be absorbed, reflected or transmitted (Fig. 1). Of the incident photosynthetically active radiation (PAR 400 - 700 nm) the leaf absorbs about 90%. The absorbed energy may be used by the photochemical system to fix carbon, be dissipated as heat or emitted as fluorescence. The energy of fluorescence emission *in vivo* represents only about 3 - 5% of the excitation energy. Variable chlorophyll$_a$ fluorescence (Fv) is closely linked to the photochemical activity of the chloroplasts and therefore can be used as a non-destructive probe of the photochemical/photosynthetic processes. These processes are influenced by many factors including the plant's status with respect to water (watering regime), nutrients (fertilizer treatment), temperature (seasonal, diurnal) and light (daylength and irradiance level).

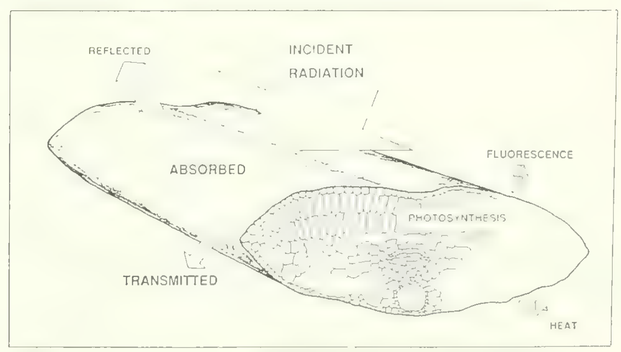

Figure 1.--Schematic drawing of a western hemlock (conifer) needle section. Disposition of the incident light (PAR) is proportional to the size of the arrows. It is this fluorescence that is the basis of Fv measurement. (Redrawn in part from Tucker and Emmingham, 1977).

MATERIALS AND METHODS

Measurement

Seedlings are dark-adapted for 15 to 20 min prior to Fv measurement. This is required to ensure an initial zero photochemical activity and CO_2 fixation state. The shoot of the dark-adapted seedling was then placed in the spherical cuvette of the integrating fluorometer (Fig. 2) (Toivonen and Vidaver, 1984) interfaced to a computer for data acquisition and analysis of Fv. Gas exchange was measured with an ADC Mk III infra-red gas analyzer

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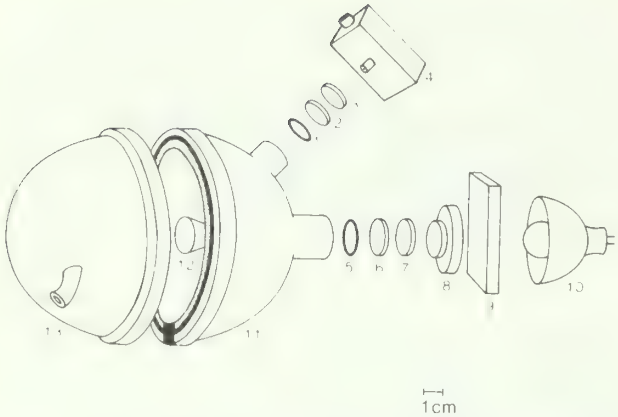

Figure 2.--Exploded view of the integrating fluorometer probe. (1) rubber O ring, (2) CS 7-59 filter, (3) CS 2-64 filter, (4) optical detector assembly, (5) O ring, (6) CS 4-96 filter, (7) CS 3-71 filter, (8) photographic shutter, (9) heat absorbing filter, (10) Sylvania EFP (100 W, 12 V) projector lamp, (11) supporting hemisphere (it supports the light and detector assembly and is fitted to a stand), (12) dispersion cone, (13) detachable hemisphere. (Reproduced from Toivonen and Vidaver, 1984).

(IRGA). Dry wt. was determined by oven drying samples at 90^{o} C for 24 h. Unless otherwise stated all Fv and gas exchange measurements were carried out at 22 - 25^{o} C.

Normalization

Once data are collected, the fluorescence (Fv) transients need to be compared. The Fv transients (curves) are normalized to compensate for differences in chlorophyll content (ie. plant size) (Fig. 3). The normalization formula uses a value for instantaneous fluorescence (F_o) (see Papageorgiou, 1975 for a review of variable chlorophyll fluorescence).

The formula is:

$$Fv = \frac{F_{\vartheta} - F_o}{F_o}$$

where Fv is normalized variable fluorescence at time t,
F_{ϑ} is non-normalized fluorescence at time t,
and F_o is O-level fluorescence

Averaging

To evaluate a seedling population or seedlot, a normalized Fv transient or induction curve for each of several seedlings is used (Fig. 4). Each curve represents more than 1000 data points obtained at a predetermined frequency over a fixed time period. Averaging is done by summing the values at each sampling point of the normalized curves, then dividing by the number of replicates. Data given in results represent the averaged response of 3 - 5 seedlings.

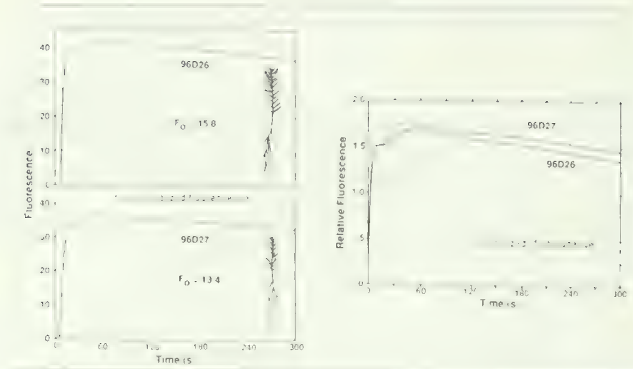

Figure 3.--The normalization operation largely compensates for differences in amplitude of individual White spruce seedling Fv curves. Non-normalized F_{ϑ} curves (left) of seedling 96D26 and 96D27 are from the same seedlot (8981).Their normalized Fv transients are compared in the right.

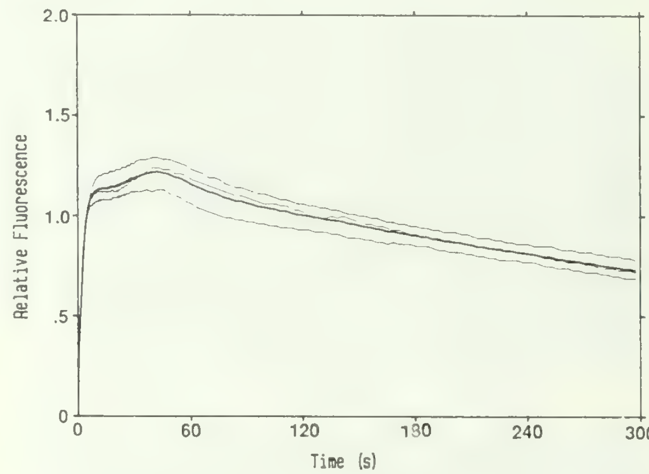

Figure 4.--Normalized Fv responses of individual White spruce seedlings (seedlot 8981) are shown as fine lines. The averaged Fv response of the three seedlings is shown as the broad line.

RESULTS

Photochemical Inactivation

Fv curves shown in Fig. 5 show a sequential decline in Fv amplitude for 1-0 White spruce container-grown stock. This decrease in fluorescence is accompanied by reductions in the rate of apparent photosynthesis (APS). The fluorescence decline represents a decrease in the rate of the primary photosynthetic process of water splitting (Toivonen and Vidaver, 1988), thus reducing the potential for photodamage in high ambient light under cold temperatures (Peeler and Naylor, 1988) when biochemical CO_2 assimilation is inhibited. Inactivation of photosynthetic activity (shutdown) is considered by us to be an indicator of the winter hardening-off process.

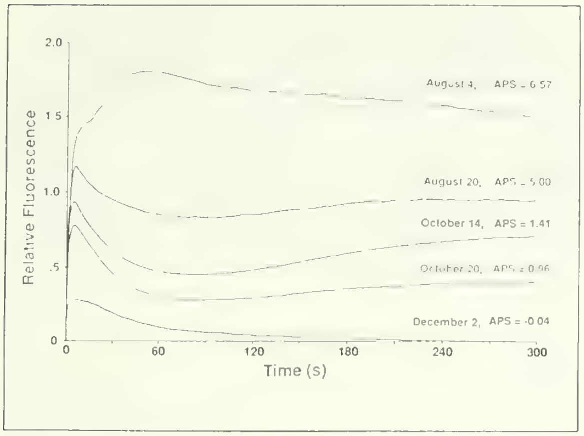

Figure 5.--Sequential inactivation of photosynthetic activity in White spruce seedlings (8981). The Fv decline with the approach of Fall reflects the inactivation of photochemical water splitting (shutdown). The decline in Fv appears to be mainly daylength dependent. These seedlings experienced no frost during the inactivation period. APS is expressed as mg CO_2 g dry wt^{-1} h^{-1}.

From this series of curves, we suggest that these seedlings could have been lifted for cold dark storage by Oct. 20. The -18 C cold hardiness tests (British Columbia Ministry of Forests (BCMOF)), (Simpson, 1985) performed immediately after Fv established that the seedlings had also achieved cold-hardiness at that time. The barely positive APS rates determined at 25° C would have been negative at ambient temperatures. The nursery operational lifting date was Dec. 2 for the same stock.

Provenance Differences in Shutdown Time

Differences were detected using Fv in the level of photochemical inactivation in two provenances of White spruce. In Fig. 6, the upper curve shows that more southern provenance seedlings (seedlot #8534, ca. 54° 50'N, Fort St. James, B.C.) had not reached the same level of inactivation by Nov. 17 as the northern provenance (#8981, ca. 57° 50' N, Fort Nelson, B.C.). The earlier progression toward shutdown in the northern provenance may indicate an adaptation to the earlier onset of winter conditions which would be experienced by these seedlings.

Recovery From Cold Dark Storage

Root growth capacity (RGC) assessment of seedling vigor following removal from cold dark storage usually takes one to three weeks (Burdett, 1979). Seedlings in which Fv had returned to near pre-shutdown levels within 48 h after removal from storage (Fig. 7, Table 1) also had high RGC scores. Seedlings exhibiting little recovery of Fv after 48 h had poor RGC's (Table 1).

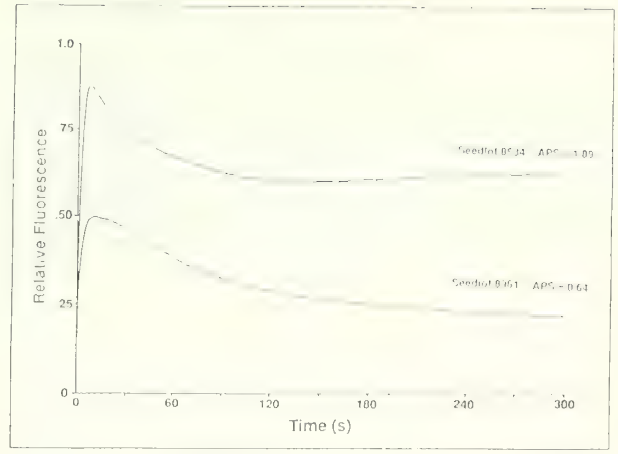

Figure 6.-- Provenance differences in the photosynthetic inactivation of White spruce seedlings. Other data as in Fig. 5.

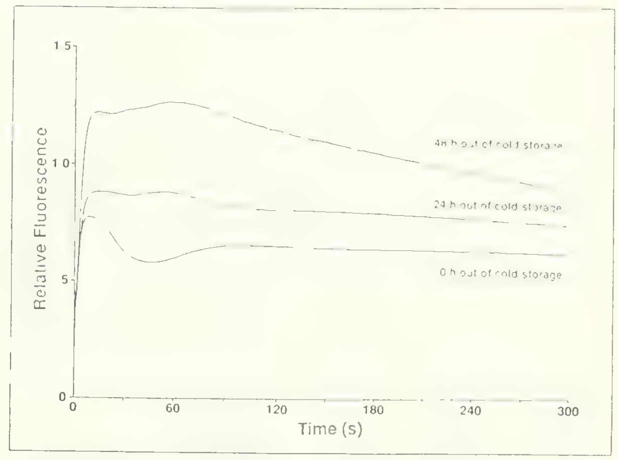

Figure 7.--Recovery of Fv on removal from cold dark storage in White spruce seedlings (seedlot 4073). On removal from storage the seedlings were repotted, watered and equilibrated to room temperature. Note that within 48 h, Fv had largely recovered to levels expected from fully active seedlings (top curve in Fig. 5).

Table 1.-- Maximum Fv values 48 h following removal from cold dark storage and corresponding RGC scores for White spruce seedlings. (Values are means ± standard errors.)

Seedlot	n=	Fv(max)	RGC
4073	5	1.28 ± 0.16	4.88 ± 0.15
8503	6	0.37 ± 0.40	0.62 ± 0.5
8782	6	0.53 ± 0.01	1.06 ± 0.44
8533	6	0.63 ± 0.2	1.13 ± 0.02

This correlation is consistent with the findings of Van den Driessche (1987) which indicated that new root growth is dependent on current photosynthetic activity.

Natural Water Stress and Recovery

From June 1 to July 15, 1987 there were large ambient temperature and relative humidity fluctuations at the growing sites (Fig. 8). This resulted in increased water stress in White spruce (seedlot #8534) seedlings on a 48 h watering cycle as indicated by both fluorescence and CO_2 exchange data (Fig. 9). When temperatures markedly declined at the beginning of July, both CO_2 exchange and Fv recovered.

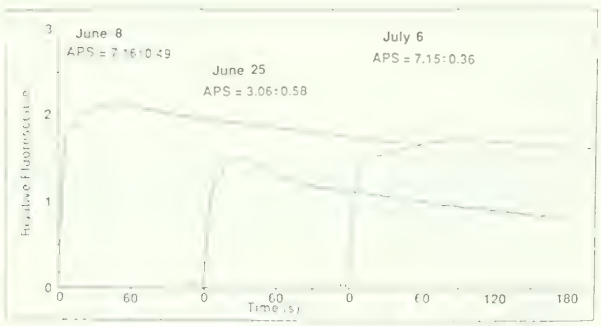

Figure 8.--Changes in Fv and APS of white spruce seedlings (seedlot 8534) under water stress occurring during the second year of the production cycle. Both June 8 and July 6 represent periods of cooler temperatures and therefore lower water stress potential. APS (mean ± standard error) given as CO_2 g dry wt^{-1} h^{-1}.

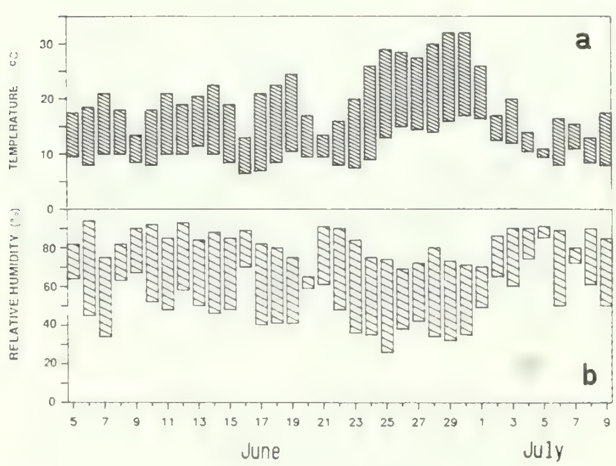

Figure 9.--Temperature range and humidity range data for the period June 5 to July 9, 1987 from a weather station at SFU. Fv and APS measurements were done on June 8 and 25, and on July 6, 1987.

Induced Water Stress and Recovery

Withholding water for various intervals induced symptoms of water stress in 2-0 seedlings of seedlot 8981. On rewatering, recovery (see Figs. 10 -11) depended on the fluctuations in temperature and humidity (Fig 12).

Seedlings last watered on July 14 exhibited mild water stress on July 16 (Fig. 10). Following watering (immediately after Fv assessment on July 16), the seedlings showed some recovery over the next day. High evaporative demand during July 17 (Fig. 12) resulted in marked water stress as indicated by reduced Fv on July 18 (Fig. 11). Following rewatering on July 18, together with lower temperatures, higher relative humidities and therefore lower evaporative demand, the seedlings recovered overnight as indicated by the July 19 Fv curve.

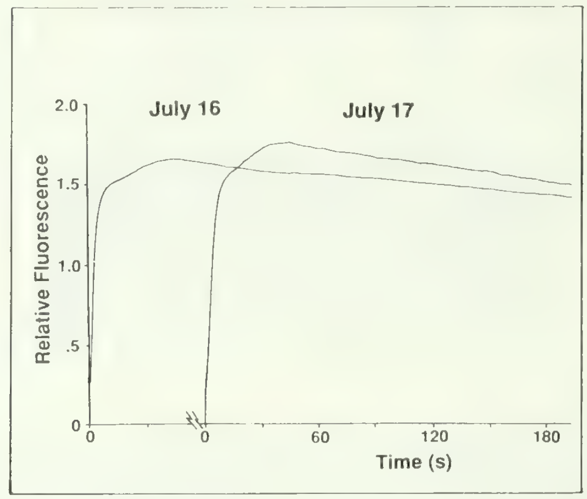

Figure 10.--Response of white spruce (Seedlot 8981) to 48 hours without water on July 16 and the recovery 18 hours after rewatering on July 17. This period of time was characterized as having a low evaporative potential.

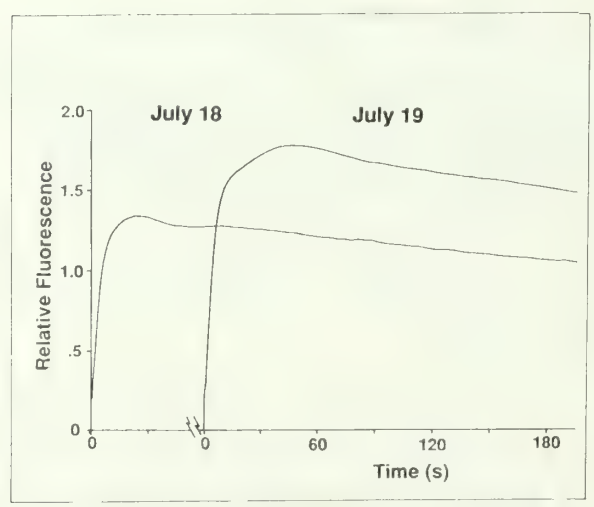

Figure 11.--Response of white spruce (seedlot 8981) to 48 hours without watering on July 18 and the recovery 18 hours after rewatering on July 19. The day prior to July 18 had relatively high evaporative potential.

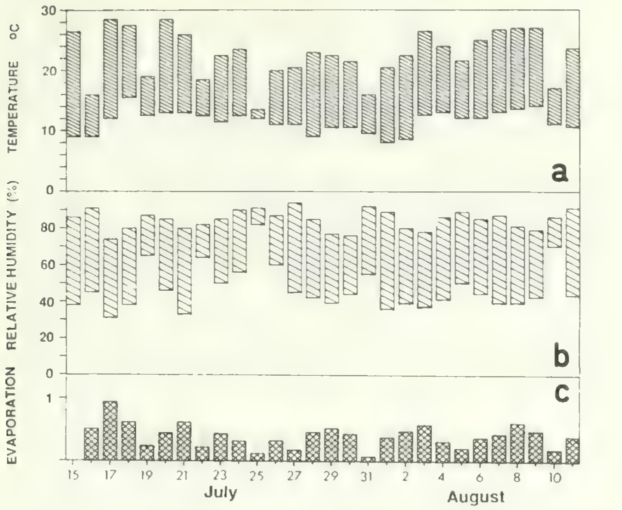

Figure 12.--Temperature range, humidity range, and relative evaporation data for the period of July 15 to August 10, 1987 from a weather station at SFU. Evaporation was measured with a Piche evaporimeter and the units are relative.

Phosphorus Nutrition

In this trial, phosphorus was applied as 20-20-20 (Green Valley) at varying frequencies during the growing season to 1-0 Douglas-fir seedlings. The frequency of P application was: every 2 wks, 4 wks, 6 wks or no application at all. All other nutrients were applied at regular 2 week cycles. The shape of the Douglas-fir Fv induction curve can be seen to be different from that of White spruce (Fig. 13). This difference is likely due to higher water-splitting activity in Douglas-fir compared to White spruce. The difference appears to be reflected in higher Douglas-fir APS rate (Fig. 13) which is typical for the seedling during the growing season. An initial effect of lowering P was observed with the treatment resulting in 0.19% P content; the initial Fv transient was slightly higher than for the control treatment while APS did not decrease significantly. At the lowest P level (right-hand curve), the initial Fv transient was still higher and APS decreased to 60% of the initial value, and the decline from the initial peak was faster. The effect of these P levels on photochemical water splitting could be associated with some decrease in the activity of the dark reactions of CO_2 assimilation.

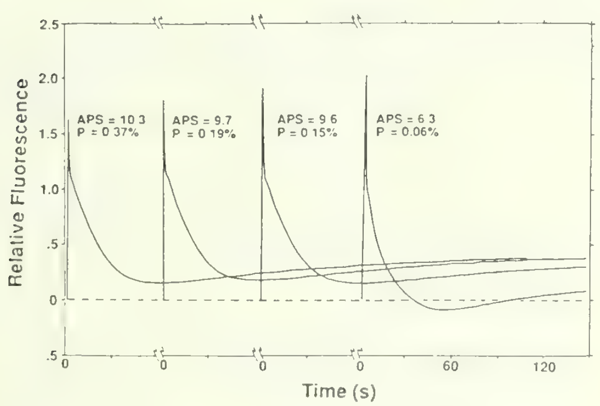

Figure 13.--Changes in Fv, APS, and phosphorus content of Douglas-fir (seedlot 1293) when P was applied (from left to right) every 2 weeks, 4 weeks, 6 weeks, or not at all during the growing season of 1987. APS units are mg CO_2 g dry wt^{-1} h^{-1}, phosphorus (P) content as % total dry weight.

DISCUSSION

Data from Fv assessment provides information about the physiological status of conifer seedlings during the nursery production cycle.

In White spruce seedlings inactivation of photochemical water splitting (shutdown) occurs primarily in response to daylength. The onset of shutdown appears to be influenced by the latitude of seedlot provenance; shutdown occurs earlier in the fall in the northern than the more southern provenance. As shutdown is presumably related to the winter-hardening process and may be indicative of the extent of hardening, Fv assessment provides information of potential advantage in the selection of pre-storage lifting dates. Any delay in lifting could result in seedlings being lifted well after the optimal date and unnecessary losses in seedling nutrient reserves could occur. Fv assessment indicates physiological reactivation in the event of a warming trend after the chilling requirement has been filled (see the bottom curve in Fig. 5. and the top curve in Fig. 7). Reactivated seedlings would likely undergo nutrient losses and possibly physical damage while in cold dark storage.

The use of Fv to assess recovery from cold dark storage by monitoring the reactivation of photochemical water splitting could provide a good indication of seedling quality. Recovery of Fv appears to be related to root function. In experiments not shown here (Vidaver, *et al.* 1988), it was observed that watered and repotted seedlings showing little or no recovery, recovered more rapidly and to a greater extent when shoots were detached and the stem was placed directly in water.

Symptoms of water stress observed with Fv assessment during periods of high evaporative demand could likewise be indicative of the failure of the seedling root system to provide sufficent shoot moisture. Episodes of partial inactivation due to water stress may result in seedling set back or failure to reach BCMOF morphological growth standards during the growing season. Operational application of Fv could alert growers to the need for more effective watering regimes or the production of more efficient root systems.

The data from the P experiments suggest that potential utilization of nutrient stress to regulate morphological development could be monitored by Fv. In withholding P, APS was suppressed which if sustained would obviously restrict seedling growth. In these experiments restoring P, rapidly resulted in the full recovery of Fv (data not shown).

SUMMARY

These preliminary results of the application of Fv assessment to the physiological status of conifer seedlings suggests that operational application of the fluorometer system to seedling production could provide substantial benefits to the nursery industry.

1] Fv measurement can provide a simple, rapid, reliable and non-destructive method of evaluating seedling physiological status during the nursery production cycle.

2] Fv measurement provides information which can be used in determining lifting dates, the effects of water stress and nutrient regimes, and for assessing post-storage vigor.

ACKNOWLEDGEMENTS

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Effect of the Timing of Cold Storage on Cold Hardiness and Root Growth Potential of Douglas-fir[1]

Karen E. Burr and Richard W. Tinus[2]

Abstract.--Container-grown Douglas-fir seedlings were cold acclimated in growth chambers over 20 weeks. At weekly intervals, cold hardiness and root growth potential (RGP) were measured, and additional seedlings were placed in 1°C storage for 4 weeks. Cold hardiness and RGP were reassessed following storage. Cold hardening continued in storage regardless of when during acclimation seedlings were stored. However, the rate of cold acclimation increased or decreased during storage depending on the level of cold hardiness at the start of the storage period. RGP generally declined during storage, though occasionally remained the same or increased without apparent relation to level of cold hardiness.

INTRODUCTION

The recent focus of tree seedling quality research has been on seedling attributes that indicate physiological condition and stress resistance, with the recognition that both morphological and physiological measures of quality are necessary (Duryea 1985, Ritchie 1984, Sutton 1979). Such physiological attributes include cold hardiness, root growth potential (RGP), and bud dormancy. There is much to be gained by understanding the interrelationships of these attributes, not only as it contributes to basic science through defining the annual physiological cycle of nursery-grown seedlings, but also from a practical perspective. Quickly measured information on cold hardiness could be used as a rapid estimator of RGP and bud dormancy, attributes more time consuming to measure, if a consistent relationship between the three could be established.

Toward this end, the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station stress physiology project at Flagstaff, Arizona has been examining the interrelationships between cold hardiness, RGP, and bud dormancy in southwestern conifers. The initial approach was to simulate that portion of the annual cycle from bud set to bud break under controlled growth chamber conditions, and to measure all three attributes concurrently at frequent intervals (Tinus et al. 1986). In this way, relationships between the attributes were established. However, these relationships were observed only under a single set of temperature and photoperiod conditions. Recently completed experiments examined the cold acclimation and deacclimation of interior Douglas-fir and the associated changes in RGP and bud dormancy using several different sets of temperature conditions. Additionally, the effects of transferring seedlings to optimum growing conditions or to cold storage at intervals throughout acclimation and deacclimation were measured. This paper presents the results from one of those cold acclimation regimes and the effects on cold hardiness and RGP when seedlings were transferred to cold storage at intervals throughout acclimation.

MATERIALS AND METHODS

Seedlings of interior Douglas-fir (Pseudotsuga menziesii var. glauca) of the same seed source as in our previous experiments (Tinus et al. 1986) were greenhouse-grown in 240-ml Rootrainer[3] book containers in a peat-vermiculite mix for 8.5 months (Mar. 17 - Dec. 1, 1987). Greenhouse temperatures averaged 25°C daily and 22°C at night. Daylength was extended to 22 hours

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[3]Trade names are used for brevity and specificity, and do not imply endorsement by the USDA to the exclusion of other equally suitable products.

with fluorescent light (7.5 umol s^{-1} m^{-2}). Watering was as needed, with a high-nitrogen complete nutrient solution (223 ppm N, 36 ppm P, 151 ppm K). Other cultural conditions were as recommended by Tinus and McDonald (1979). Actively growing seedlings were then placed in Percival HL-60 growth chambers for a 2-stage, 20-week cold acclimation regime. Day/night temperatures were 20°/15°C during the first 4-week stage, and 10°/3°C during the second 16-week stage. Daylength was 10 hours throughout the 20 weeks (518 umol s^{-1} m^{-2}). Watering was as needed, with a low-nitrogen complete nutrient solution (20 ppm N, 86 ppm P, 151 ppm K).

A random sample of 24 seedlings was taken from the growth chamber population at weekly intervals. Needle tissue was removed from each seedling for a freeze-induced electrolyte leakage (FIEL) test of cold hardiness. The seedlings were then randomly divided into two equal groups, with one group used in an aeroponic RGP test, and the other placed in 1°C storage for 4 weeks. Cold hardiness of the stored seedlings was measured with the FIEL test weekly, or after 1, 2, and 4 weeks, during the 4-week storage period. RGP of the stored seedlings was measured at the end of the storage period.

Cold Hardiness Test

The FIEL test procedures to measure needle tissue cold hardiness were similar to those previously described (Burr et al. 1986). Needles were removed from the second to the last flush along the central axis of each seedling in the sample to be tested. An equal number of needle segments, 1 cm long, cut at both ends, were prepared from each seedling. Segments were pooled into four equal groups such that the trees represented by each group were the same every time testing was conducted. The segments were washed in distilled water and transferred to culture tubes containing 0.5 ml distilled water. Each group of segments was used to fill six tubes, six needles per tube.

The 24 tubes were then divided into sets of 4 such that each set included 1 tube from each of the 4 groups of segments. In this way, four groups of seedlings within each sample were independently monitored. One set of tubes was stoppered and placed in a refrigerated water bath at 1°C as a control. The other 5 sets of treatment tubes were placed in a Forma Scientific ethanol bath at -2°C. After 0.5 hour, the water in the treatment tubes was nucleated and the tubes were stoppered. The ethanol bath was then cooled at the rate of 5°C per hour.

At each of 5 test temperatures, selected to span 20 to 80% injury, 1 set of treatment tubes was removed to thaw in the 1°C water bath. After all tubes were removed from the ethanol bath and thawed, 5.5 ml of distilled water were added to each of the 24 tubes, and all were stoppered and placed in a 100-rpm shaker at 24°C for 20 hours incubation. Conductivity of the solution in each tube was measured after incubation with a YSI conductance meter and microcell, and the tubes were then placed in a boiling water bath for 15 minutes to induce complete tissue injury. Conductivity was remeasured after an additional 20 hours incubation in the shaker.

Test results, which were available in 2 days, were measured as percent index of injury according to Flint et al. (1967). A modified Gauss sigmoid model (Grosenbaugh 1965) was fitted to each data set, and the temperature at 50% index of injury (LT50) was estimated by inverting each model.

Root Growth Potential (RGP) Test

RGP was measured using an aeroponic system similar to that described by Burr et al. (1987). The mist chamber measured 1.0 m wide x 2.4 m long x 0.6 m high, was constructed of 5-cm-thick rigid urethane foam, and was fitted with a copper tubing, 3-nozzle mist system 25 cm above the floor of the chamber. Conditions within the chamber were maintained at 100% relative humidity and 27°C by a warm-water intermittent mist and a 10-cm layer of vermiculite in the bottom of the chamber. Rootballs, with potting mix intact, were suspended within the chamber using foam-lined redwood seedling clamps which formed the top of the chamber. RGP tests were conducted in a greenhouse with day/night temperatures averaging 21°/18°C and a 22-hour photoperiod extended with fluorescent light (7.5 umol s^{-1} m^{-2}).

RGP was quantified as the total number of new roots per seedling ≥0.5 cm in length after 14 days in the mist chamber. Means and standard errors were calculated for each sample of 12 seedlings.

Storage Treatment

The 1°C storage treatment was maintained in a 1.5 m x 0.7 m x 1.3 m cooler. Stored seedlings were kept in darkness except when removed from the cooler for weekly sampling of tissue for the FIEL test and for watering, which was as needed with the low-nitrogen nutrient solution. Seedlings, in the book containers, were placed upright in the cooler without wrapping or packaging.

RESULTS

Cold Hardiness

Douglas-fir cold hardiness increased from -5°C to -32°C during the 2-stage, 20-week growth chamber cold acclimation regime that excluded exposure to freezing temperatures (fig. 1). Cold acclimation proceeded slowly during the first 4-week stage when day/night temperatures were 20°/15°C. When day/night temperatures were lowered to 10°/3°C in the second stage, cold acclimation proceeded rapidly, reaching a maximum rate of approximately 1°C per day during the ninth week. Maximum cold hardiness, under these conditions, was reached in 14 weeks. No further cold acclimation occurred between week 14 and week

20, though cold hardiness may have oscillated somewhat. Cold hardiness as a function of time was highly predictable under these conditions. The LT50's for the entire 20-week period were regressed using a weighted least squares non-linear regression assigning higher weight to early weeks (R^2= .983).

Cold acclimation continued during the 4-week, 1°C storage period regardless of when seedlings were stored during the 20-week acclimation regime (fig. 2). This change in seedling environment, from growth chamber to storage conditions, was accompanied by an increase or decrease in the rate of cold acclimation, depending on the level of cold hardiness at the start of the storage period. Seedlings stored in weeks 0 through 2, with cold hardiness between -5° and -6°C, acclimated more rapidly in storage than seedlings remaining under growth chamber conditions. Seedlings stored in weeks 3 through 10, which included the period of most rapid cold acclimation in the growth chambers, acclimated more slowly in storage than seedlings remaining under growth chamber conditions. Seedlings stored in weeks 11 through 20 continued to cold acclimate appreciably in storage, while seedlings remaining under growth chamber conditions reached maximum cold hardiness and stopped acclimating.

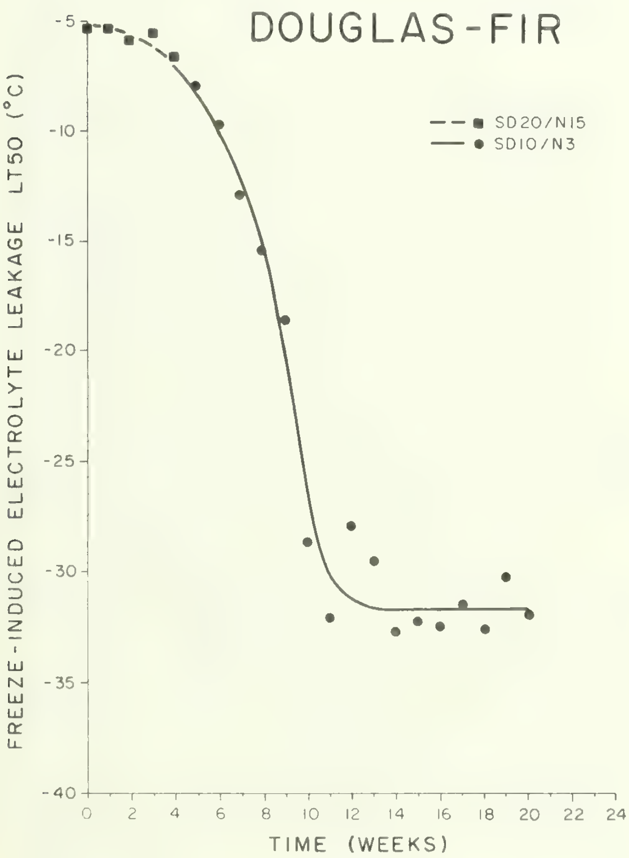

Figure 1.--Temperatures resulting in 50% index of injury to needle tissue in the FIEL test (LT50), as a function of time under growth chamber conditions. R^2= .983
$LT50 = -31.83 + 26.27e \exp(-0.000031W^{4.706})$
where W= week.
Dashed line = short day 20°C, night 15°C.
Solid line = short day 10°C, night 3°C.

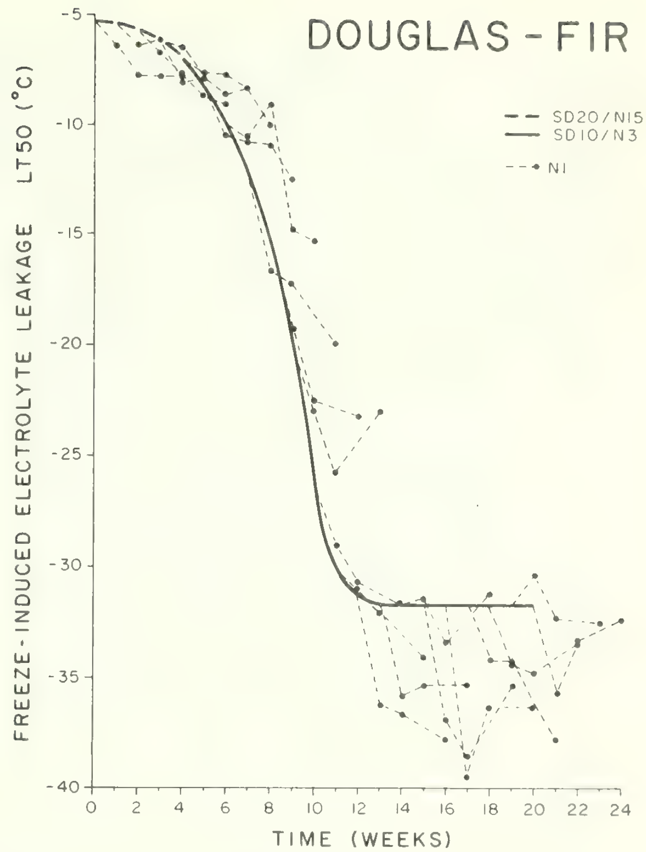

Figure 2.--Regression of 50% injury temperatures from figure 1, with temperatures resulting in 50% index of injury to needle tissue when seedlings were transferred at weekly intervals to 1°C storage (N1) for 4 weeks.

Root Growth Potential (RGP)

Douglas-fir RGP, measured as total number of new roots per seedling at 14 days, increased from 55 to 145 during the 20-week growth chamber cold acclimation regime (fig. 3). The initial rapid rise in RGP from 55 to 125 new roots per seedling coincided with the period of rapid cold hardening during the first 12 weeks. When seedling cold hardiness was at or near maximum under the growth chamber conditions, weeks 12 through 20, RGP remained high but fluctuated widely.

RGP generally declined during the 4-week, 1°C storage period, though occasionally remained the same or increased without apparent relation to the level of cold hardiness at the start of the storage period (fig. 4). However, RGP after 4 weeks storage increased from 25 new roots per seedling placed in storage week 0 to almost 130 new roots per seedling placed in storage week 20.

DISCUSSION

Cold Hardiness

The pattern of cold acclimation (fig. 1) was similar to that measured in the previous growth chamber experiment with this seed source (Burr et al. 1986, Tinus et al. 1986). However, the maximum rate of cold acclimation was twice as fast as previously measured. Seedlings in the current experiment reached an LT50 7°C lower than seedlings in the previous experiment did in the same length of time. Changes in greenhouse cultural conditions during seedling production to prevent bud set and promote active growth until the start of the current experiment, such as a reduction in moisture stress through more frequent watering, may have predisposed the current crop of seedlings to cold acclimate faster. Timmis and Tanaka (1976) observed that severe moisture stress under long days reduced the rate of Douglas-fir cold acclimation, while mild stress under long days enhanced cold acclimation when both treatments were followed by short days at low temperatures. Cold hardening to -20°C without exposure to freezing temperatures has been previously observed in other conifers (Glerum 1973, Cannell and Sheppard 1982) but hardening to -30°C and below

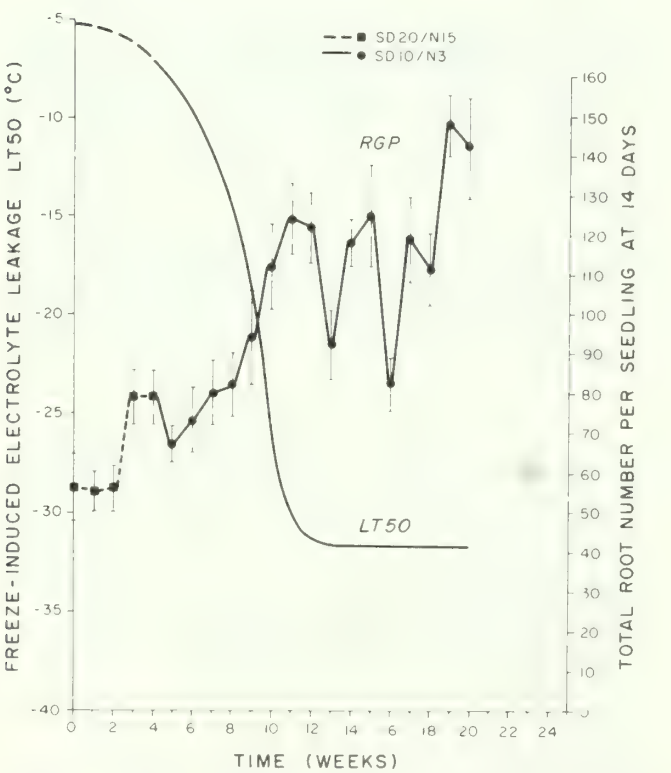

Figure 3.--Total number of new roots per seedling at 14 days (RGP) as a function of time under growth chamber conditions, with regression of 50% injury temperatures from figure 1 (LT50). Vertical bars are ±1 standard error. Standard errors ranged from 5 to 15, with a median of 8.

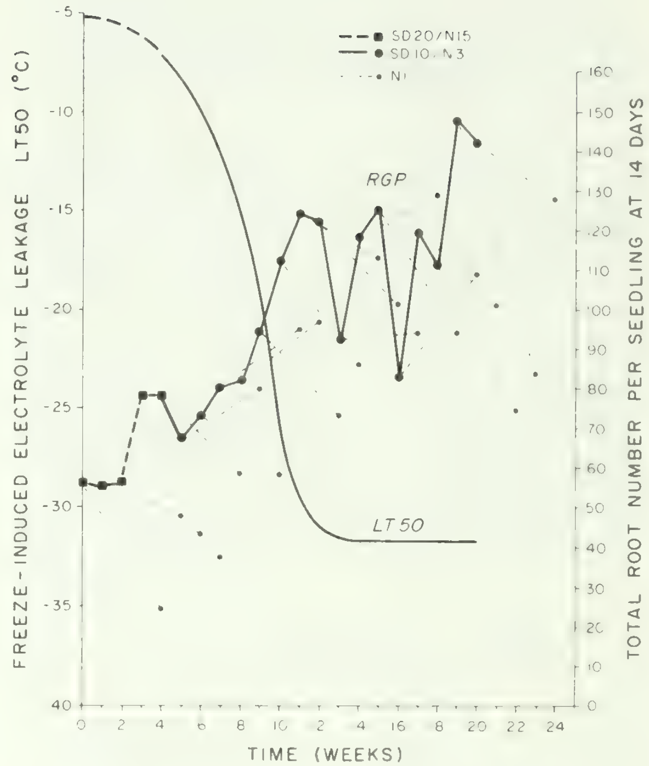

Figure 4.--Total number of new roots per seedling at 14 days (RGP) before (as in fig. 3) and after transfer at weekly intervals to 1°C storage (N1) for 4 weeks, with regression of 50% injury temperatures from figure 1 (LT50).

was of interest, especially since this FIEL tissue test was found to be approximately 10°C more conservative than a whole-plant freeze test LT50 estimate in this hardiness range (Burr et al. 1986).

The continuation of cold hardening in storage, regardless of when during acclimation seedlings were stored, and the restarting of the hardening process in storage after cold hardiness had stabilized under growth chamber conditions, suggest the importance of temperature, in the absence of photoperiod, for regulation of seedling physiology (fig. 2). Changes in the rate of cold acclimation were not random, but occurred in a readily identifiable pattern when seedlings were transferred from the growth chamber conditions into storage. It is anticipated that the extension of this pattern of rate changes over longer storage periods will result in a stabilizing of seedling cold hardiness throughout a wide range of LT50's such that the greater the level of cold hardiness at the start of storage, the lower the final LT50 attained. The lowest attainable LT50 for a sample of seedlings stored at any point along the acclimation curve would then be a function of genotype, production history, acclimation history, and storage conditions.

This seed source may or may not respond similarly to other handling and storage conditions. It should be noted that the container seedlings in this experiment were stored upright, with undisturbed root systems, good air circulation, and regular watering. Thus, many of the stresses associated with standard lifting, packaging, and storing procedures were minimized. This may have been critically important for the continuation of the cold hardening process in storage. Faulconer (1989) reported bareroot coastal Douglas-fir seedlings, lifted and packaged using operational procedures, deacclimated in storage unless stored when cold hardy to at least -15°C. A comparison of the two studies suggests that the stresses associated with the lift and pack process may disrupt physiological mechanisms permiting continued cold hardening in storage (Faulconer 1988).

Root Growth Potential

The RGP pattern (fig. 3) was similar to that previously measured for this seed source under cold acclimating growth chamber conditions (Tinus et al. 1986). RGP of the seedlings in both experiments was low when cold hardiness was minimum, increased rapidly during the period of rapid cold acclimation, and remained high but fluctuating when cold hardiness was maximum. The resolution of the pattern has been improved in the current experiment by more frequent measurement and the use of larger sample sizes. There are many reports of conifer seedling RGP increasing under natural conditions during the cold acclimation period (DeWald and Feret 1987, Jenkinson 1980, Ritchie and Dunlap 1980) and the pattern presented here was comparable. The relationship between the rapid increase in cold hardiness and the rapid rise in RGP, consistent in both this and the previous experiment, further supported the hypothesis that such relationships exist.

Storage was generally detrimental to seedling RGP throughout the cold acclimation period (fig. 4). There was no indication of an increase in seedling capacity to maintain RGP in storage as cold acclimation progressed. There are, however, many reports that early-lifted bareroot seedlings store poorly, losing RGP in storage, while fully hardy seedlings store without loss of RGP, and often with increased RGP, under storage temperatures and durations similar to those used in this experiment (DeWald and Feret 1988, Ritchie and Dunlap 1980). An explanation for this difference is not readily available. Until it becomes possible to identify and monitor the physiological changes occurring during storage that are manifested as a change in RGP, it will remain difficult to explain why RGP increases, decreases, or remains unchanged during any given period of time.

Though there was a general decline in RGP during storage throughout the acclimation period, RGP levels following storage increased with time as cold hardiness at the onset of storage increased. Seedlings stored after cold acclimating to at least -15° to -20°C maintained RGP levels during the 4-week storage period at least as high as unstored seedlings at the start of the acclimation period. Thus it was still possible to increase RGP over the initial level of 55 new roots per seedling, with a 4-week storage period, by placing seedlings in storage after a moderate level of cold hardiness was attained.

In summary, this was the second experiment in which Douglas-fir seedlings of a single seed source were cold acclimated in growth chambers at the U.S. Forest Service Flagstaff facility. The patterns of cold acclimation and RGP, as well as the relationship between the two patterns, were consistent in both experiments. At weekly intervals throughout the acclimation period, seedlings were placed in 1°C storage for 4 weeks. Cold acclimation continued in storage, though the rate of acclimation was altered in a predictable manner. RGP generally declined in storage, though RGP levels after storage increased with greater cold hardiness at the onset of storage. Effects of longer storage periods on cold hardiness and RGP remain to be determined.

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Basamid and Solar Heating Effective for Control of Plant-Parasitic Nematodes at Bessey Nursery, Nebraska[1]

Diane M. Hildebrand[2] and Gary B. Dinkel[3]

Abstract.--Methyl bromide/chloropicrin, Basamid®, and solar heating were compared for control of *Fusarium* spp., plant-parasitic nematodes and weeds at Bessey Nursery, Halsey Nebraska. All treatments controlled nematodes. Solar heating and polyethylene-sealed Basamid were less effective than methyl bromide for control of *Fusarium* spp. Water-sealed Basamid did not control *Fusarium* spp. Only methyl bromide and solar heating controlled weeds. A windstorm after treatment may have confounded results.

INTRODUCTION

In order to control damping-off fungi and other soil-borne fungal pathogens, plant-parasitic nematodes, and weeds, pre-plant fumigation with methyl bromide/chloropicrin is used on a regular basis at most Federal tree nurseries (Ruehle, 1986). Due to health hazards, alternative chemicals and cultural practices are continually being tested. In summer, 1985, the Manager at Bessey Nursery (Halsey, Nebraska) requested an evaluation of Basamid® as an alternative chemical fumigant, especially for control of plant-parasitic nematodes.

Basamid® (dazomet) reacts with moist soil to form methyl isothiocyanate, a degradable biocide. The fumigant vapors are kept in the soil by surface compaction and sealing with water. Polyethylene sheeting may be required for the sandy soil at Bessey. Basamid has been reported as effective in controlling weeds, nematodes, and soil-borne fungal pathogens (Neumann et al., 1984; Hopkins Co.).

An alternative to chemical fumigation is soil solar heating. Solar heating of soil is accomplished by covering moist soil with clear polyethylene sheeting for several weeks during midsummer. Solar heating has reduced populations of weeds and soil-borne fungal pathogens in forest tree nurseries (Cooley 1985; Hildebrand 1987). A previous study of solar heating effects on nematode populations at Bessey resulted in no observable treatment effect because of very low and highly variable population levels of plant-parasitic nematodes (Hildebrand 1985). Positive effects on tree seedling survival have not yet been demonstrated in forest nurseries, but a fall-sown crop would be the most likely to show benefit.

The objective of this evaluation was to compare soil treatments with methyl bromide/chloropicrin (Dowfume® MC-33), Basamid® Granular, and solar heating for effectiveness in reducing populations of species of *Pythium*, *Fusarium*, plant-parasitic nematodes, and weeds. Comparisons were planned also for effects on growth and survival of fall-sown eastern redcedar (*Juniperus virginiana* L.).

MATERIALS AND METHODS

Soil treatments for fall-sown eastern redcedar were begun in summer 1986 at Bessey Nursery. The portion of the nursery unit chosen for this evaluation showed nematode damage in the eastern redcedar crop lifted in spring 1986. The limited area with high nematode concentrations and the need to prevent cross-contamination between treatments necessitated limited replication.

Five treatments were replicated in two plots of 10 x 40 ft arranged as in figure 1. At the time of sowing, the tractor formed and sowed beds first in the methyl bromide/chloropicrin plots, then the polyethylene-covered Basamid plots, then the water-sealed Basamid plots, then the solar-heated plots, and finally the check plots. This sequence helped minimize contamination of the treated beds during sowing because the intensity of the biocidal effects of the treatments were expected to follow the same order. This plot layout helped ensure the presence of sufficient nematodes in all treatments. The nursery bed area adjacent to the treatment area was

[1]Paper presented at the Western Forest Nursery Association Meeting, Vernon, British Columbia, August 8-11, 1988.

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|<-----------------------160-ft-------------------->|

|<--------- Eastern redcedar windbreak -------->|

	S	S	C	C	M
North Edge	WB	WB	PB	PB	M
	M*	M*	M	M	M

Figure 1.--Treatment plot layout: S = Solar-heated, C = Check, WB = Water-sealed Basamid, PB = Polyethylene-sealed Basamid, M = Methyl bromide/chloropicrin, M* = M plots for this study.

fumigated with methyl bromide/chloropicrin and the entire unit was sown to easter redcedar following normal nursery practices.

Treatments

1. (M) Fumigation with Dowfume® MC-33 (67% methyl bromide and 33% chloropicrin) at 350 lb per acre in late July, 1986. The chemical was injected into the soil and the soil surface sealed with polyethylene sheeting for 5 days and then the polyethylene was removed.

2. and 3. Basamid® Granular (Hopkins Co.) was spread evenly over the soil surface at 350 lb per acre and tilled into the top 8" in late July, 1986. The water-sealed (WB) plots were packed flat with a bed packer, and sealed by light irrigation. The water seal was repeated once to prevent surface cracking. The polyethylene-sealed (PB) plots were irrigated lightly and covered with 1.5 mil clear polyethylene sheeting for 10 days. After 10 days the four Basamid plots were cultivated to facilitate dispersal of fumigant vapors. Several oat seeds were sown in one check, one PB, and one WB plot 2 weeks after cultivation to test for residual toxicity.

4. (S) Solar-heated plots were watered to field capacity and covered with 1.5 mil clear polyethylene for 6 weeks beginning in early July, 1986. The polyethylene was removed immediately before sowing.

5. (C) No chemicals were applied to check plots. Check plots remained under the sudan grass cover crop until mid-July, 1986.

In order to maximize benefit from soil treatments, the sudan grass cover crop was plowed under about 2.5 weeks prior to each treatment. Beds were formed and eastern redcedar sown and mulched (covered with clear polyethylene and lathe board) three weeks after cultivation of the Basamid plots.

Sampling

Soil samples were taken a few days before treatment and a few days before sowing. One 6" core was taken with a soil bucket auger (3" diameter) for each sample, with 5 samples per treatment plot. The bucket was wiped clean of soil between samples.

A small portion of each sample was assayed for population levels of species of _Pythium_ and _Fusarium_ at the Rocky Mountain Region Forest Pest Management Lab. Standard assay procedures developed by Forest Service Plant Pathologists for the Reforestation Improvement Program (Landis 1986) were used except for the selective media. The selective medium for _Pythium_ spp. was from Hendrix and Kuhlmann (1965) and for _Fusarium_ spp. from Nash and Snyder (1962). The rest of the soil from each sample was shipped to Peninsu-Lab (Kingston, Washington) for assay for plant-parasitic nematodes.

Fungal populations were again assayed in mid-June, 1987. Plant-parasitic nematodes were again assayed by Peninsu-Lab in soil samples taken in late July, 1987. The number of weeds per 3 sq ft and the percentage of weed cover were determined in mid-May, 1987, in 6 sample areas per treatment plot. Weeds were then removed by hand in the treatment plots. The number of living, dying, and dead eastern redcedar seedlings were counted every 3 to 4 weeks in 6 sample areas per treatment plot beginning in mid-May, 1987. Dying seedlings were examined for causal agents and number of seedlings per square foot were determined. Final seedling counts were made in late July, 1987.

Temperatures

Soil temperature data for solar heated and check plots were taken during previous studies at Bessey Nursery (Hildebrand 1987), and were not gathered for this evaluation.

RESULTS

Two weeks after cultivation of the Basamid treatment plots, germination of oats indicated no residual toxicity, and sowing was completed on schedule. Because sample variances were quite heterogeneous, the test for equality of means with unequal variances was used for all comparisons (Sokal and Rohlf, 1981).

Fungi

Population levels of *Pythium* spp. were too low to show any treatment effects. Population levels of *Fusarium* spp. were significantly decreased only by the methyl bromide (M) and solar (S) treatments (figure 2). Methyl bromide treatment was more effective than solar heating in reducing population levels of *Fusarium*. In both Basamid (PB and WB) treatments, *Fusarium* populations were concentrated in pockets, while those in solar plots were more evenly distributed at low levels. Between pretreatment and post treatment samples, *Fusarium* levels in check plots increased significantly while those in each Basamid treatment remained statistically similar. By the following June, 1987, *Fusarium* levels increased (not significantly except in M plots) in all treatments, but levels in M, S, and PB treatments were significantly lower than in check and WB treatments. Population levels of *Fusarium* spp. greater than 1000 propagules per gram of oven-dried soil are expected to cause noticeable damping-off in susceptible species.

Nematodes

Population levels of plant-parasitic nematodes in the check and PB plots were significantly higher than in other plots before treatment. Population levels remained high in the check plots, while being significantly reduced by all other treatments (figure 3). The chemical treatments, M, PB, and WB, were equally effective, and somewhat more so than solar heating. The nematode levels remaining in the solar plots were below the threshhold for seedling damage (200 nemas per pint of field moist soil), based on previous sampling in healthy and diseased eastern redcedar at Bessey Nursery. By the following July, 1987, nematode levels were still at potentially damaging levels in check plots, while remaining low in all other treatments.

Weeds

In mid-May, 1987, the predominate dicotyledonous weed was mare's tail or horseweed, *Conyza canadensis* (L.) Cronq., while the predominate grassy weed was downy brome, *Bromus tectorum* L. The average number of weeds and percentage weed cover in the treatment plots are summarized in figure 4. Numbers of weeds were significantly reduced compared to checks only in methyl bromide and solar plots. Weed cover was significantly reduced only in solar plots. Weeds and weed cover in the Basamid plots were not significantly reduced compared to that in check plots.

Temperatures

Temperature data from a previous study at Bessey (Hildebrand 1987) is presented in figure 5. Highest temperatures averaged 8°C higher in solar than in check plots. Average high temperatures recorded at 30 cm depth were much lower than near

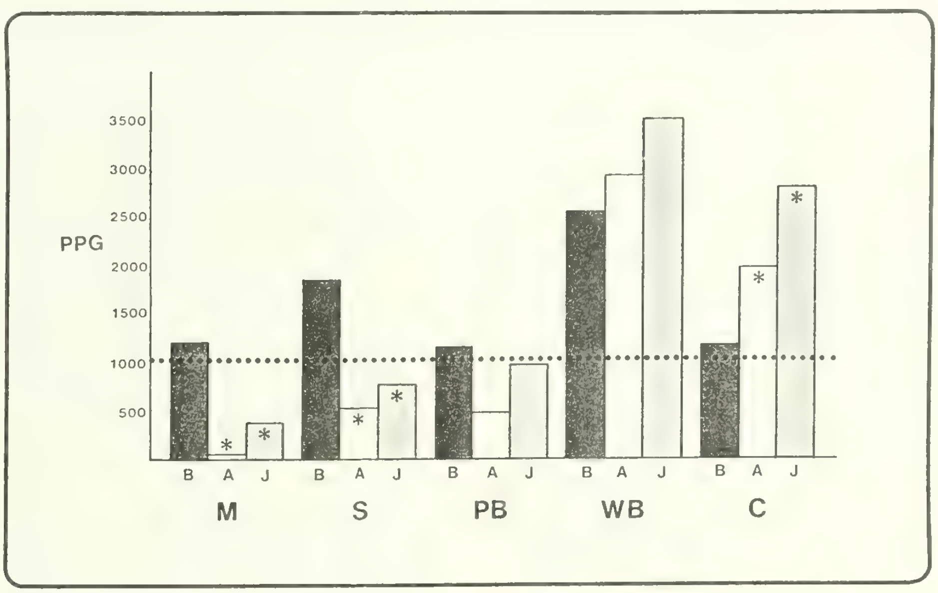

Figure 2.--Means and their significance for population levels of *Fusarium* spp. in propagules per gram of oven-dried soil (PPG) in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots before (B) and after (A) treatment in summer 1986, and the following June (J) 1987 at Bessey Nursery. Asterisks indicate significant difference (P<0.05) from the before treatment mean.

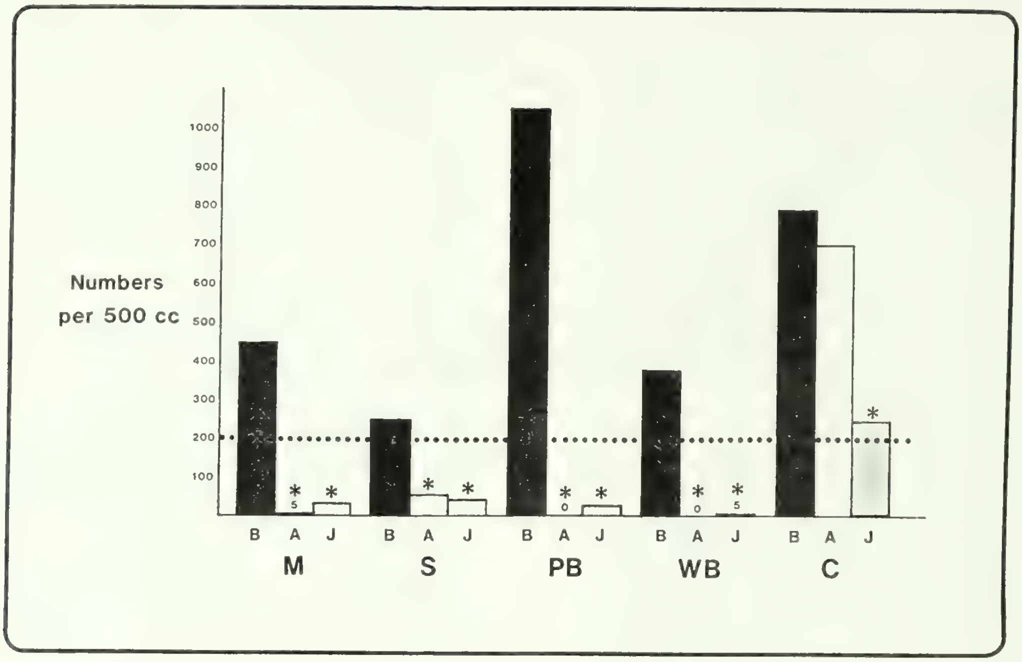

Figure 3.--Means and their significance for population levels of plant-parasitic nematodes (numbers per pint of soil) in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots before (B) and after (A) treatment (summer 1986), and the following July (J) 1987 at Bessey Nursery. Asterisks indicate significantly different (P<0.05) from the before treatment levels.

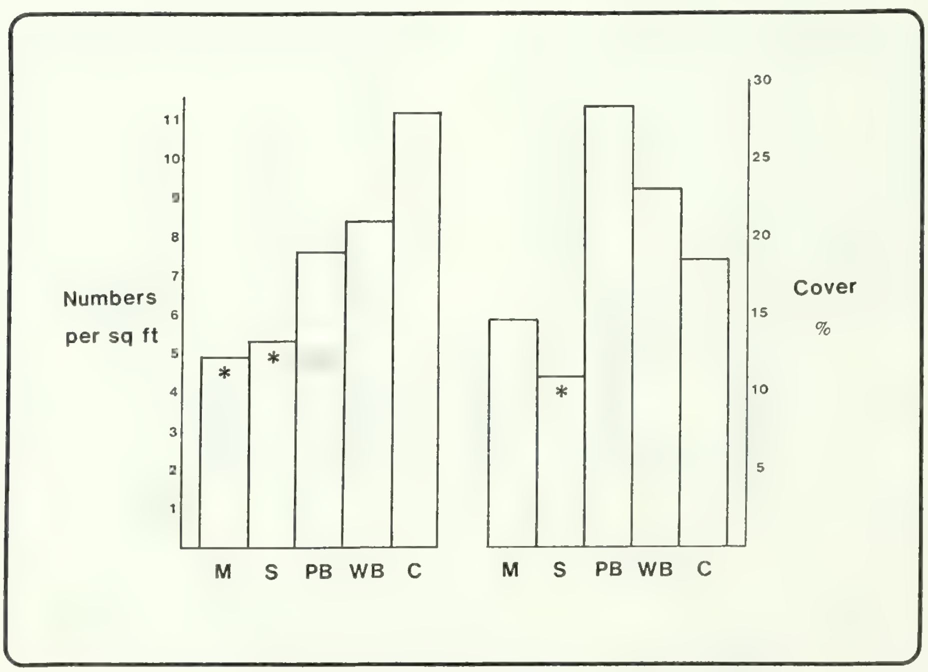

Figure 4.--Means and their significance for weed numbers (per sq ft) and weed cover in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots in May 1987. Asterisks indicate significantly different from check.

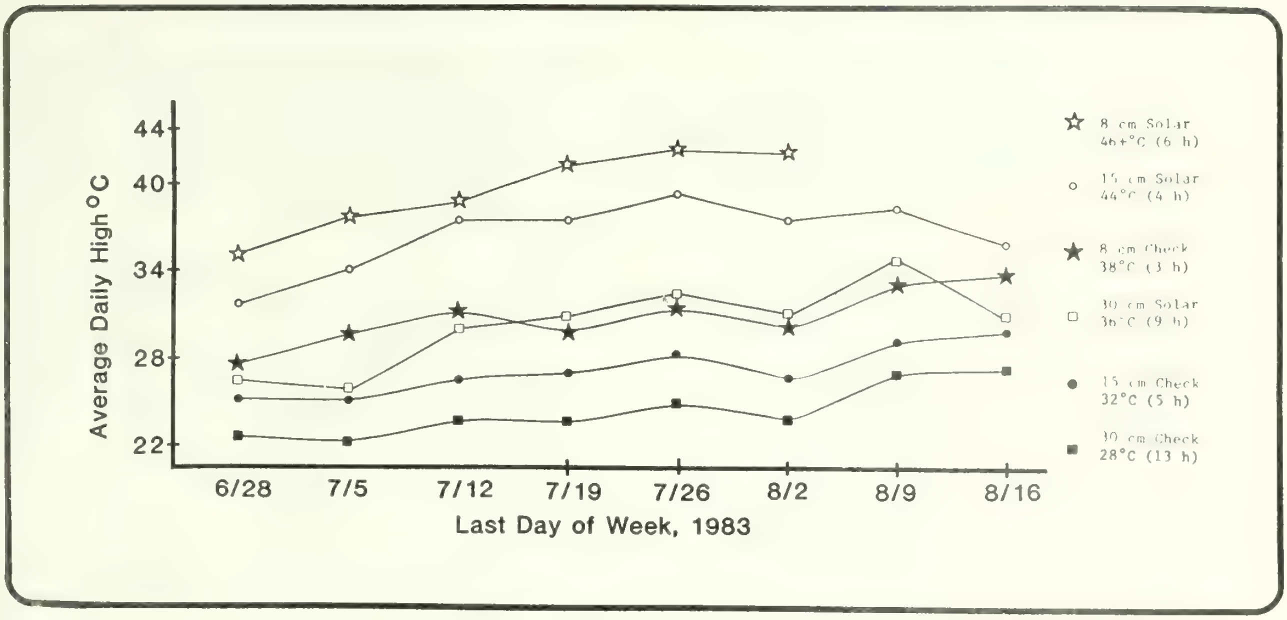

Figure 5.--Weekly averages of daily high temperatures recorded by thermographs buried at 8, 15, and 30 cm in one solar and one check plot at Bessey Nursery, 1983. Highest temperature achieved and the duration in hours (h) that the temperature remained within 1°C of the the high is given for each thermograph.

the surface (8 cm), but temperatures remained within 1°C of the daily highs much longer at greater depth. At 8 cm in the solar plot, 46°C (the limit of the recording capability of the thermograph used) was exceeded several times. At these times, the temperature remained above 45°C for 2 to 6 hours, averaging 4.1 hours. While the temperature was off-scale (46+°C) on August 2 at 8 cm in the solar plot, the recording chart tore and the subsequent record was lost.

Seedling Survival

Eastern redcedar seedlings succumb to damping-off caused by Fusarium spp., but only rarely (0.6% in this study). Seedling survival in May and July 1987 is presented in Table 1. Stocking in all treatments was far less than the standard 25 seedlings per square foot. So few seedlings survived frost damage early in the spring that those remaining were more susceptible to sun scorch and burial by blowing sand.

Table 1.--Average number of seedlings per square foot in treatment plots: methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C), in May and July 1987 at Bessey Nursery.

	M	PB	WB	S	C
May	11.4	0.1	6.8	0.1	0.1
July	9.9	0.1	5.2	0.1	0.1

DISCUSSION

According to soil assays, Basamid was as effective as fumigation with methyl bromide/chloropicrin for controlling plant-parasitic nematodes. Solar heating was effective in reducing populations of plant-parasitic nematodes, but not quite as effective as chemical fumigation.

For reducing populations of Fusarium spp., methyl bromide fumigation was best, followed by solar heating and polyethylene-sealed Basamid. The heavy windstorm prior to sowing may have contributed many of the fungal propagules that increased the variability in population levels of Fusarium in post treatment samples. Vaartaja (1967) showed that fungal reinfestation of fumigated soil occurs by blowing dust. If the concentrated pockets of Fusarium in the Basamid plots were a result of Basamid treatment, use of Basamid would probably result in pockets of losses for most conifers. Movement of soil by wind or equipment would spread the inoculum. Since many conifers are susceptible to Fusarium root rot later in the season, cumulative losses could be high. Use of solar heating might have similar results, but to a lesser extent.

In this evaluation, solar-heating was the most effective treatment for weed control. The windstorm also blew many weed seeds into the study area after treatments. Even in the area treated with methyl bromide, more weeds than usual were observed under the clear polyethylene sheeting used as winter mulch over the eastern redcedar beds. Consequently, the weed control results may not adequately compare the efficacy of the treatments.

An early warming period in late winter, 1987, resulted in seedling emergence early in March. The polyethylene sheeting was removed March 12-13, 1987. Snow and cold weather followed, resulting in heavy losses to frost injury. Because of the sheltering effect of the windbreak, seedlings near the windbreak (S and C plots) were slower to emerge and were very susceptible when the frost occurred. So few seedlings survived that the treatment area was plowed under following soil sampling in July, 1987. The Nursery will try black polyethylene sheeting as mulch for subsequent eastern redcedar crops, to prevent much of the "greenhouse" warming that occurs under the clear sheeting.

Overall, fumigation with methyl bromide/ chloropicrin was the most effective treatment. Based on the results of this evaluation, solar-heating and possibly polyethylene-sealed Basamid could be fairly effective substitutes for methyl bromide fumigation. Water-sealed Basamid could be used only for nematode control. Further evaluations for weed and disease control should be done with larger treatment areas and other conifer crops. The cost of treatment with polyethylene-sealed Basamid is higher than methyl bromide fumigation, but handling may be less hazardous. Solar heating is much less expensive than chemical fumigation.

<u>Disclaimer</u>

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Occurrence and Persistence of *Fusarium* within Styroblock and Ray Leach Containers[1,2]

R.L. James, R.K. Dumroese, and D.L. Wenny[3]

Abstract.--Fusarium spp. are common pathogens of containerized conifer seedlings. They often colonize inner walls of styroblock and Ray Leach® pine cell containers. Highest amounts of Fusarium were detected at the bottom of cells. As many as 95 percent of the cells at some nurseries, sampled prior to cleaning, were colonized with Fusarium. Hot water cleaning and dipping in bleach solutions reduced, but did not eliminate these fungi within containers. Fumigation with methyl bromide was no more effective than standard hot water treatments for styroblock containers; however, it was more effective in reducing levels of Fusarium within pine cells. Contaminated containers may be an important inoculum source of these pathogens for subsequent seedling crops.

INTRODUCTION

Fusarium spp. cause important diseases of containerized conifer seedlings in northern Rocky Mountain nurseries (James 1984a, 1986). Most conifer species are susceptible to these fungi, but losses are often greatest on Douglas-fir (Pseudotsuga menziesii (Beissn.) Franco), western larch (Larix occidentalis Nutt.), and Engelmann spruce (Picea engelmannii Parry)(James 1984a, 1985b; James and Gilligan 1985). Several investigations were previously conducted to help understand the disease cycle on containerized seedling stock to improve efficacy of control techniques. One important aspect of these investigations involves determining possible sources of Fusarium inoculum for seedling infection. It has been shown that seed (James 1984b, 1986, 1987), soil mixes (James 1985a), and greenhouse debris such as weeds (James and others 1987) may all act as important inoculum sources. However, experience in some nurseries has shown these potential sources do not provide enough inoculum to account for the high disease levels encountered. Therefore, investigations were conducted to ascertain the relative abundance of Fusarium inoculum on containers reused several times to grow successive crops of seedlings. Evaluations were also made on the relative efficacy of standard cleaning techniques to reduce inoculum.

MATERIALS AND METHODS

Styroblocks and Ray Leach® pine cells were analyzed from several different container nurseries in the northern Rocky Mountains (table 1). Sampling intensity varied among the nurseries, but analysis techniques were similar. Styroblock cells were selected for sampling using a random number generator. Pieces of styroblock adjacent to the inner wall were aseptically cut from selected cells and placed, inside surface down, on an agar medium selective for Fusarium (Komada 1975). Usually 2-4 pieces of styroblock were collected from each cell. Although most samples were collected from the bottom of cells, some samples were taken higher up the cell. Pine cells were sampled similarly with pieces cut from the bottom of cells. Sampling was designed to determine: 1) percentage of cells colonized with Fusarium and 2) a measure of colonization intensity which roughly indicated density of fungal propagules within cells available for infection of seedlings. Plates with container pieces were incubated at about 22-24° C under cool

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[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Intermountain Nursery Association, and the Forest Nursery Association of British Columbia. [Vernon, British Columbia, Aug. 8-11, 1988].

[2]Idaho Forest Wildlife and Range Experiment Station Contribution No. 404.

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fluorescent light for 5-7 days. The number of pieces from which Fusarium grew, as well as an approximation of the percentage of the piece colonized, were determined.

Table 1. Northern Rocky Mountain nurseries sampled for occurrence of Fusarium spp. on containers.

Container Type	Nursery and Location
Styroblock	Plum Creek, Pablo, MT Champion Timberlands, Plains, MT Potlatch Corporation, Lewiston, ID Western Forest Systems, Lewiston, ID University of Idaho, Moscow, ID
Ray Leach® Pine Cell	USDA Forest Service, Coeur d'Alene, ID

Cells were sampled both before and after cleaning. Cleaning techniques varied somewhat among the different nurseries. In most cases, cleaning consisted of washing containers with hot water under pressure. Some nurseries added commercial cleansers such as Saniclean® and followed the water treatment with immersions in a bleach solution. In one case, styroblocks and pine cells were fumigated with methyl bromide (under polyethylene tarps) following standard hot water cleaning. Some containers were also sampled several months after being cleaned. These containers were either stored outside or within greenhouses or warehouses.

Comparisons between "cleaned" and "uncleaned" container cells were made using standard "t" tests. Percentages underwent arc-sin transformation prior to analysis.

RESULTS AND DISCUSSION

Extent of styroblock container colonization by Fusarium spp. varied widely among the nurseries sampled (table 2). For example, levels at the Plum Creek and University of Idaho nurseries were generally lower than those at the Champion Timberlands, Potlatch, and Western Forest Systems nurseries. At Plum Creek and Potlatch nurseries there were also some differences in Fusarium colonization of containers sown with different seedlots. In most cases, standard cleaning significantly (P=0.05) reduced amount of Fusarium within containers, although high residual populations often remained. Fusarium spp. were isolated from the bottom of cells more frequently than from near the top. These fungi were also often isolated from root pieces that penetrated the side walls of cells and were not removed during cleaning.

Table 2. Occurrence of Fusarium spp. on styroblock containers from five nurseries in the northern Rocky Mountains.

			Percent of Cells Colonized with Fusarium					
			Prior to Cleaning			After Cleaning		
Nursery[1]	Seedlot	No. Cells Sampled	Top	Bottom	Both	Top	Bottom	Both
Plum Creek	631	50	6	16	22*	0	6	6*
	632	50	12	20	28*	2	14	14*
	17045	50	6	34	36*	2	16	16*
	Totals	150	8	23	29	1	12	12
Champion	-	100	44	-	44NS	12	65	65NS
Potlatch	Spur 10	50	20	86	88*	0	18	18*
	Camp 55	50	22	92	96*	2	36	36*
	Robinson	50	18	86	86*	2	20	20*
	Blackwell	50	12	76	76*	2	18	18*
	Totals	200	18	85	86*	2	24	24*
Western Forest Systems	-	60	13	93	95*	15	65	67*
University of Idaho	FN	80	-	44	44NS	-	33	33NS

[1] See table 1 for nursery locations.

* Denotes significant differences (P=0.05) in Fusarium colonization of cells prior to and after cleaning.

NS Denotes no significant differences (P=0.05) in Fusarium colonization of cells prior to and after cleaning.

Table 3. Occurrence of Fusarium spp. on Ray Leach® pine cells from the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Prior to Cleaning	After Cleaning	After Cleaning and Storage	All Samples
Percent Cells Infected	86*	51*	52*	65
Percent Colonization Intensity	88*	69*	72*	76

[1] Percentage of pine cell pieces colonized with Fusarium.

* Denotes significant differences (P=0.05) in Fusarium colonization of cells prior to cleaning and after cleaning or after storage.

At the USDA Forest Service Nursery, Coeur d'Alene, ID, 86 percent of pine cells sampled prior to cleaning were infected with Fusarium spp. (table 3). This was reduced to about 50 percent by standard steam cleaning. However, storage in a warehouse for several months failed to significantly reduce Fusarium populations within pine cell containers.

Treatment of styroblock containers with methyl bromide had no effect on occurrence of Fusarium (table 4). Percent of cells colonized with these fungi were similar before and after methyl bromide treatment. On the other hand, the fumigant significantly reduced percentage of pine cells which were colonized with Fusarium. Differences in effectiveness of methyl bromide between the different types of containers may be due to the ability of the fumigant to penetrate the container side walls or problems with methodology.

Table 4. Effects of methyl bromide fumigation on occurrence of Fusarium within styroblock and Ray Leach® pine cell containers.

		Percent Cells Colonized with Fusarium	
Container Type	Cells Sampled	After Cleaning	After Methyl Bromide
Styroblock	100	22.5NS	26.3NS
Pine Cells	120	55.5*	29.2*

* Denotes significant differences (P=0.05) in Fusarium colonization of cells before and after methyl bromide treatment using a standard "t" test.

NS Denotes non-significant differences (P=0.05) in Fusarium colonization of cells before and after methyl bromide treatment using a standard "t" test.

The most common species of Fusarium isolated from containers was F. oxysporum Schlect. Other major species included F. sambucinum Fuckel, F. tricinctum (Corda) Sacc. and F. acuminatum Ell. & Ev. Some of these isolates were probably pathogens whereas others were likely saprophytic. Pathogenicity tests will be required to evaluate how extensive the occurrence of pathogenic strains of Fusarium are in isolates from containers.

Our investigations indicated styroblock and pine cell containers commonly harbor Fusarium inoculum after being used to grow a crop of container seedlings. Standard techniques for cleaning containers after use are ineffective in reducing amounts of Fusarium to very low levels. Experience indicates that the more containers are used to grow several crops of seedlings, the more they become contaminated with these fungi. Several managers use older containers to grow species like ponderosa pine (Pinus ponderosa Laws.), which are not damaged by Fusarium as much as other conifer species (James and Gilligan 1988).

These investigations also showed that standard techniques of hot water, steam, and bleach treatment are relatively ineffective in reducing Fusarium to acceptable levels. Methyl bromide was also not very effective, especially in styroblocks. However, some growers in Canada have begun to use sodium metabisulfite, a chemical used in fermentation, to clean containers and report good success (Dennis and Sturrock 1988).

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Styroblock Sanitization: Results of Laboratory Assays from Trials at Several British Columbia Forest Nurseries[1]

Rona N. Sturrock and John J. Dennis[2]

Abstract.—Moss and algae build-up on used styroblocks and an increase in root diseases of container-grown forest nursery seedlings in British Columbia prompted investigation of improved methods for sanitizing used styroblocks. Current block washing methods, pasteurization treatments, and several biocides were tested for their efficacy against algae and pathogenic fungi. Assays of treated styroblock pieces cultured on media in the laboratory indicate that pasteurization treatments reduced algae and virtually eliminated pathogenic fungi. Three biocides, i.e., captan, sodium metabisulfite, and methyl bromide were equally effective against pathogenic fungi. Additional testing of these and other sanitizing methods is needed to provide growers with a choice of block washing methods.

INTRODUCTION

In British Columbia forest nurseries conventional cleaning agents for used styroblocks include sodium hypochlorite (common household bleach) diluted with water and soaps specially formulated to kill moss and algae. Depending on when seedlings are lifted, styroblocks are either washed immediately after seedling removal or they are overwintered on the nursery site and washed before seed sowing. Some nurseries use sophisticated block washing machines; others use home-made dip tanks or heavy pressure hoses to wash blocks. Recent losses of seedlings to root diseases indicate that these cleaning procedures are only partially effective.

Molded from expanded polystyrene beads, styroblocks deteriorate over time, especially with heavy use. Cracks and holes which develop in the styrofoam accumulate root pieces and other organic debris which harbor fungi, algae, mosses, and insect eggs. This phenomenon cannot be overlooked in British Columbia for two important reasons: 1) enhanced production of container seedlings means prolonged use of styroblocks, e.g., blocks at some nurseries have been used for 7 to 10 seasons; and 2) an expanding 2+0 container seedling program means seedling roots are present in styroblock cavities for long periods.

Recognizing the need for an effective cleaning procedure for used styroblocks, British Columbia Ministry of Forests and Canadian Forestry Service extension personnel, and staff at both Ministry and private nurseries undertook cooperative styroblock sanitization trials which are described here. Although the trials were originally initiated because of concerns over moss and algae build-up on used styroblocks, laboratory assay results showed that inoculum of pathogenic fungi such as Fusarium survive even rigorous styroblock washing. The first two trials tested conventional washing techniques (i.e. bleach and soap washes) against pasteurization (i.e. using heated water or other solutions or steam for a few minutes at 100°C or less to reduce microbial populations). The remaining trials tested the efficacy of several biocides as sanitizing agents.

MATERIALS AND METHODS

Trial I: Conventional Washing Versus Pasteurization

Nine block washing treatments were tested for sanitizing used styroblocks (Table 1). The styroblocks treated were of uniform age and had been used several years. The stainless steel tank used for pasteurization treatments (3 to 7) accommodated one block at a time. Tank water was heated and the temperature was maintained by using an acetylene torch to heat air being circulated by a fan through a curved steel pipe inside the tank. Treated styroblocks were randomly sampled soon after treatment by cutting ten 60 x 10 mm pieces from each block with a hand saw. The saw was sterilized with 70% ethyl alcohol after each sample. To determine post-treatment survival of fungi, 80 pieces from each treatment were transferred to petri plates containing one of four culture media (20 pieces on each medium): a Pythium-selective medium (PA) (Hendrix and Kuhlman 1965) with the antibiotic Nystatin added (Eckert and Tsao 1962); a Pythium-selective V8 juice medium (PPA) (Peninsu-Lab, Kingston, WA 1984); a Fusarium- selective medium (KM) (Komada 1975); or a general medium, Difco (Difco Laboratories, Detroit, MI) acidified potato dextrose agar (APDA). To determine survival of algae, 10 block pieces per treatment were placed in test tubes containing either Bristol's Solution (BS) (Bold 1942), a

[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Intermountain Nursery Association and Forest Nursery Association of British Columbia. [Vernon, British Columbia, August 8-11, 1988].

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Table 1.—Conventional washing versus pasteurization treatments of used styroblocks: Trial I.

Treatment	Description
1	Styroblocks washed[1] and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v).
2	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of sodium hypochlorite (6% household bleach) (1:11 v/v).
3	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 30°C.
4	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 50°C.
5	Styroblocks washed and dipped for 3 minutes in a tank containing water at 80°C.
6	Styroblocks washed and dipped for 1 minute in a tank containing water at 100°C.
7	Styroblocks washed and dipped for 3 minutes in a tank containing water at 100°C.
8	Styroblocks washed (control).
9	Styroblocks not washed (unwashed control).

[1]All styroblocks were washed with water in a block washing machine before subsequent treatment.

general medium for algae, or soil algae agar (SAA) (Poindexter 1971), a solid culture medium specific to fresh water and soil algae. Plates and tubes were incubated at room temperature under prevailing daylight for up to 8 weeks. Fungi growing from the styroblock pieces were identified as to genus and the colonies were counted. Algae colonies were not identified but were assessed as either present or absent.

Trial II: Conventional Washing Versus Pasteurization

Treatments 1, 5 and 9 from Trial I were repeated and five new pasteurization treatments were assessed (Table 2). The chamber used for treatments 5 through 7 was a standard greenhouse steam sterilizer approximately 1.07 m in diameter x 1.5 m in length. To prevent warping of the styroblocks, the steam was bled off intermittently to maintain the chamber temperature at 80 to 82°C. This meant that the styroblocks received a steam condensate treatment rather than a 100°C steam treatment. Treated styroblocks were sampled as in Trial I, but block pieces (20 per medium from each treatment) were plated on to only three culture media: KM, PA, and SAA. Numbers of fungi occurring on each styroblock piece were counted instead of counting

Table 2.—Conventional washing versus pasteurization treatments of used styroblocks: Trial II.

Treatment	Description
1	Styroblocks washed[1] and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v).
2	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 80°C.
3	Styroblocks washed and dipped for 1 minute in a tank containing water at 80°C.
4	Styroblocks washed and dipped for 3 minutes in a tank containing water at 80°C.
5	Styroblocks washed and placed for 3 minutes in a steam chamber (80 to 82°C @ approximately 55 kPa).
6	Styroblocks washed and placed for 5 minutes in a steam chamber (80 to 82°C @ approximately 55 kPa).
7	Styroblocks washed and placed for 3 minutes in a steam chamber (80 to 82°C; no pressure).
8	Styroblocks not washed (unwashed control).

[1]All styroblocks were washed with water in a block washing machine before subsequent treatment.

individual fungus colonies, as in Trial I. Algae colonies were assessed as in Trial I.

Biocide Trials

From fall 1987 to spring 1988 growers tested several biocides for sanitizing used styroblocks. Test conditions were not consistent due to the operational aspect of these trials. Styroblocks tested had been used for at least two growing seasons. The more promising treatments are summarized in Table 3. These included dips in captan (treatment A1) and in various concentrations of heated and non-heated solutions of sodium metabisulfite (treatments B, C1, C2, and C3, and D). Also known as anhydrous sodium metabisulfite (ABS) and sodium pyrosulfite, this free-flowing white, fine granular product is commonly used as (i) an anti-fermentative agent to kill naturally occurring yeasts in brewing and winemaking, (ii) a preservative for fruits and vegetables, and (iii) a dechlorinating agent in the production of colored paper. It is available in both technical and food grades. When mixed with water, ABS is mildly acidic and releases sulfur dioxide (SO_2) at a rate increasing with temperature. Potassium metabisulfite, which was tested in treatment A, is a product very similar to ABS. Testing continued with ABS because of its availability in commercial quantities.

Biocides tested which showed little or no effectiveness against pathogenic fungi included a detergent (G.H. Wood Detergent-

Table 3.—Summary of biocide treatments of used styroblocks.

Treatment		Description
A		Pieces of used, unwashed styroblocks dipped for 10 seconds in the following (all pieces air dried after treatment):
	1	a 0.016% solution of Captan 50WP.
	2	a 1.25% solution of potassium metabisulphite ($K_2S_2O_5$).
	3	water (control).
B		Pieces of used, unwashed styroblocks dipped for 6 seconds in the following solutions of anhydrous sodium metabisulfite (ABS) ($Na_2S_2O_5$), (a) immediately after solution was mixed or (b) 16 hours after mixing (b) (all pieces air dried after treatment):
	1a,b	ABS- 0.313% solution.
	2a,b	ABS- 0.625% solution.
	3a,b	ABS- 1.25% solution.
	4a,b	ABS- 2.5% solution.
	5a,b	ABS- 5% solution.
	6a,b	ABS- 10% solution.
	7	Pieces of used, unwashed styroblocks dipped for 6 seconds in water (control).
C		Pieces of used, unwashed styroblocks dipped for 6 seconds in the following solutions of ABS (a) immediately after solution was mixed or (b) 16 hours after mixing (all pieces air dried after treatment):
	1a,b	ABS- 2.5% solution.
	2a,b	ABS- 5% solution.
	3a,b	ABS- 10% solution.
	4	Styroblocks washed, placed under plastic tarp and fumigated with 100% methyl bromide at 0.6 kg/m³.
	5	Pieces of used, unwashed styroblocks dipped for 6 seconds in water (control).
D		Styroblocks washed and dipped for 20 seconds in the following solutions of ABS (all blocks rinsed with water then air dried after treatment):
	1a,b,c	ABS- 1.25% solution at 4, 40 & 70°C.
	2a,b,c	ABS- 2.5% solution at 4, 40 & 70°C.
	3a,b,c	ABS- 5% solution at 4, 40 & 70°C.
	4a,b,c	ABS- 10% solution at 4, 40 & 70°C.
	5a,b,c	ABS- water at 4, 40 & 70°C (controls).

Germicide 2004), Agribrom (a bromine based, oxidizing biocide; Tayama et al. 1986), Lysofume (a disinfectant containing formaldehyde), and two metalaxyl-benomyl (Ridomil-Benlate) solutions. Treated styroblocks were sampled as in Trials I and II but block pieces (approximately 10 per medium from each treatment) were plated on to only two culture media: KM and PA. Fungi were assessed as in Trial II. Presence or absence of algae was not determined.

RESULTS AND DISCUSSION

The results of laboratory isolations for fungi and algae from used styroblocks treated in Trial I are given in Table 4. In general, pasteurization (i.e. heat) treatments were more effective for sanitizing used stryroblocks than conventional cleaning treatments (i.e. soap and bleach). Although treatment 7 (3 min at 100°C) yielded the fewest colonies of pathogenic fungi and also reduced algae, this treatment is not considered practical because 100°C distorts styroblocks. The same is true for treatment 6 (1 min at 100°C). Thus, in terms of reducing algae and pathogenic fungi, treatment 5 (3 min at 80°C) is considered the best of the nine treatments, followed by the heated soap and bleach treatments 4, 3, and 2. These results suggest that heating water and soap solutions improves their ability to kill pathogenic fungi. High temperatures (e.g. 80 and 100°C) also appear to kill algae more effectively than moderate temperatures (e.g. 50°C), soap, and bleach treatments. Given that the mechanism of sterilization by heat involves protein denaturation (Davis et al. 1973), these results are not surprising. The 0.05% sodium hypochlorite solution (treatment 2) was clearly ineffective against algae, although it reduced pathogenic fungi. Because materials containing organic matter (e.g. used styroblocks) react rapidly with the Cl_2 component of a sodium hypochlorite solution, reducing its ability to disinfect (Davis et al. 1973), bleach may not be a wise choice for sanitizing used blocks. Using more concentrated bleach solutions will get around this problem somewhat but this may not be desirable to nursery personnel. Of the four media used to isolate fungi, KM and PA were the most selective for the pathogenic fungi of interest. The soil algae agar proved better than Bristol's solution for assessing algae survival.

Isolation results from styroblocks treated in Trial II are given in Table 5. The steam chamber treatments were generally more effective at sanitizing used styroblocks than the hot water dip and conventional treatments. Treatment 7 (3 min of steam chamber, no pressure) yielded no pathogenic fungi and most block pieces were completely clean. Treatment 5 (3 min of steam chamber) was also effective against pathogenic fungi with only small amounts of Fusarium and Phoma occurring. However, these two treatments differed in their

Table 4.—Results of trial I: conventional washing versus pasteurization.

Treatment[2]	Colonies[1] of pathogenic fungi				Percentage plates (SAA) or tubes (BS) yielding algae	
	Pythium	Fusarium	Cylindro-carpon	Phoma	SAA	BS
1	21	22	10	17	100	100
2	9	6	8	16	100	100
3	7	13	3	5	100	100
4	2	11	1	7	100	100
5	0	0	0	10	50	70
6	2	4	0	7	100	70
7	0	0	0	1	100	60
8	28	35	10	15	100	100
9	13	17	16	5	100	100

[1]Total number of colonies from four media (except for treatment 9 where three media were used) and 20 plates per medium (except for treatment 5 where 10 plates per medium were used).

[2]See table 1 for descriptions of treatments.

efficacy against algae. Treament 5 was most effective against algae, followed by treatments 4 (3 min at 80°C), 3 (1 min at 80°C), and then 7. Reasons for these differences are difficult to explain. Treatments should be repeated and sample numbers increased to determine whether there was a real treatment difference. Interestingly, treatment 2 (soap at 80°C) yielded fewer pathogenic fungi than both treatments 3 (1 min at 80°C) and 1 (soap alone). These results also indicate that there is an additive cleaning effect when both soap and heat are combined. More stringent trials would determine the best combination of soap or water, exposure time, and temperature for sanitizing used styroblocks. Because laboratory assay results from treatment 6 (5 min of steam chamber) show it to be substantially less effective against fungi and algae than treatment 5 (3 min of steam chamber), it is suspected that a technical error occurred in treatment 6.

Results of laboratory assays for fungi from styroblocks treated in the Biocide Trials are given in Table 6. Pythium spp. are not included in this Table as none were isolated. Several biocide treatments were as effective as the two best pasteurization treatments in Trials I and II in that they drastically reduced or eliminated all pathogenic fungi. The captan solution (treatment A1) killed all fungi on blocks. Given that captan is a broad-spectrum protectant fungicide used on a wide range of pathogenic fungi, this result was not unexpected. While non-heated solutions of ABS ranging in concentration from 0.313 to 2.5% reduced but did not completely eliminate all fungi, concentrations of 5 and 10% generally did. Perhaps the acidity of these concentrated ABS solutions kills fungi on used blocks. Heating solutions of ABS from 4°C to 40°C and 70°C over several ranges of concentrations (i.e. 1.25 to 10%) did not appear to enhance their biocidal effect. This is in contrast to results from heated soap treatments in Trials I and II. Because the evolution of SO_2 from ABS solutions increases with temperature, it is possible that the material decomposes more rapidly at high temperatures, thus reducing its biocidal activity. Treating blocks approximately 1 day after mixing ABS solutions (treatments B and C) did not affect the material's performance. This might be important if block washing occurs over 1 or more days. Blocks treated with methyl bromide (treatment C4) also yielded no fungi in laboratory assays.

CONCLUSIONS

The results of these trials emphasize the importance of sanitizing used styroblocks and indicate that several suitable block washing techniques are available to growers. Before deciding on a particular scheme growers should consider several factors: (i) the history of disease and algae problems at the nursery; (ii) the costs of setting up a completely new or different system, or modifying their present system; and (iii) the pros and cons of the several treatments identified in these trials. For example, a pasteurization system will require some source of energy (e.g. gas, oil) for heating solutions or generating steam, plus specialized tanks and temperature gauges for maintaining and monitoring treatment conditions. While there are no hazards from toxic materials in such systems, high-temperature solutions and pressurized air must be handled carefully.

Biocide treatments are often a more practical alternative to pasteurization because they require relatively little specialized equip-

Table 5.—Results of trial II: conventional washing versus pasteurization

Treatment	Percentage[1] styroblock pieces yielding one or more pathogenic fungi				Percentage styroblock pieces yielding algae on SAA
	Pythium	Fusarium	Cylindro-carpon	Phoma	
1	7.5	82.5	27.5	47.5	100
2	0	0	7.5	0	87.5
3	0	25	5	17.5	80
4	0	2.5	0	12.5	56
5	0	2.5	0	5	55
6	5	37.5	20	40	100
7	0	0	0	0	81
8	17.5	100	62.5	50	100

[1]Percentages based on total fungi from two media and 20 plates per medium.

ment. However, these materials must be handled with extreme caution because of their potential toxic effects on nursery workers and seedlings. Product information on sodium metabisulfite warns that the material is irritating to the eyes, nose and throat and can be very irritating to the skin. Contact with skin and eyes and inhalation of dust and SO_2 should be avoided by wearing protective equipment such as rubber gloves, safety glasses or goggles and a proper respirator. Exposure to a concentration of SO_2 of 500 ppm by volume in air for a few minutes is very dangerous. A threshold limit value of 5 ppm for sulfur dioxide (concentrations in air to which nearly all workers may be repeatedly exposed during an 8-hour work day without adverse affects) was recommended by the 1968 American Conference of Governmental Industrial Hygienists (Baker and Mossman 1970). Experience with ABS in British Columbia has also shown that it can corrode block washing equipment. Materials such as methyl bromide, while a very effective biocide, are potentially very dangerous. Growers opting for this treatment must take all necessary precautions to ensure the safety of the nursery staff and, increasingly, their suburban neighbors.

To date, one small-scale trial with lettuce seeds sown into styroblocks treated with ABS concentrations of 2.5, 5, and 10% and one operational trial where several hundred blocks were washed with a 5% ABS solution, then rinsed and sown to conifers, suggest that at these concentrations, ABS is not phytotoxic.[1]

[1]Gates, W. 1988. Personal communication. British Columbia Ministry of Forests, Silviculture Branch Extension Services, Surrey Nursery, Surrey, B.C.

With nursery practices constantly changing (e.g. growing media, container types), the kinds and numbers of disease and other organisms may also change. These changes should be monitored and styroblock sanitization techniques properly tested and modified accordingly.

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Table 6.—Laboratory assay results of biocide trials.

Treatment[2]	Percentage[1] styroblock pieces yielding pathogenic fungi: Fusarium	Cylindrocarpon	Phoma
A1	0	0	0
A2	0	0	0
A3	40	5	0
B1a	10	20	5
B1b	25	85	30
B2a	0	50	5
B2b	0	45	5
B3a	5	45	15
B3b	0	25	30
B4a	0	20	5
B4b	0	0	0
B5a	0	0	0
B5b	0	0	0
B6a	0	0	0
B6b	0	0	0
C1a	0	0	0
C1b	0	0	0
C2a	0	0	0
C2b	0	0	0
C3a	0	0	0
C3b	0	0	0
C4	0	0	0
C5	45	20	10
D1a	0	15	25
D1b	10	20	15
D1c	10	5	0
D2a	0	5	40
D2b	0	20	35
D2c	35	25	10
D3a	0	0	0
D3b	0	5	10
D3c	0	0	0
D4a	0	0	0
D4b	0	0	15
D4c	0	0	0
D5a	25	65	25
D5b	15	90	15
D5c	5	90	0

[1]Percentages based on total fungi from two media and 10 plates per medium.
[2]See table 3 for descriptions of treatments.

Douglas-fir Seed Treatments: Effects on Seed Germination and Seedborne Organisms[1,2]

R. Kasten Dumroese, Robert L. James, David L. Wenny, and Carma J. Gilligan[3]

Abstract.--Treating Douglas-fir seed prior to stratification with bleach, after stratification with hydrogen peroxide or ethanol, or soaking seed after stratification in 55.5° C water significantly reduced seedborne Fusarium levels while maintaining high cumulative germination.

INTRODUCTION

Fusarium root disease is an important problem in container nurseries of the Intermountain West. It is especially widespread and damaging to Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco). The primary source of inoculum is thought to be infested seed (James 1985a, 1986), although recent observations indicate inoculum is also carried from one year to the next in both styroblocks (James and others 1988a) and Ray Leach® pine cells (James and Gilligan 1988), even those vigorously cleaned.

Many attempts have been made to eliminate or reduce pathogenic organisms on conifer seedcoats. Many of these treatments rely on chemical sterilants, including sodium hypochlorite (Wenny and Dumroese 1987, James and Genz 1981), and hydrogen peroxide (Barnett 1976, Trappe 1961).

Recent work by Sauer and Burroughs (1986) showed corn and wheat seeds treated with 100% ethanol or sodium hypochlorite with lowered pH had decreased levels of Fusarium. Dodds and Roberts (1985) discuss a combination treatment for sterilizing seed for micropropagation. This treatment begins with a 1-3 minute soak in a 70% (v/v) ethanol solution followed by a soak in sodium hypochlorite.

One other approach to reducing seedborne pathogens is hot water treatments (Baker 1962). Hot water treatments have effectively been used on agricultural crops to reduce or eliminate seedborne pathogens while maintaining high germinative capacity without phytotoxic reactions (Neergaard 1977, Walker 1969). A recent innovative approach to hot water treatments is the use of microwaves to heat water to the desired temperature (Lozano and others 1986).

Because of the importance of seedborne inoculum in Fusarium root disease on Douglas-fir, we compared the relative efficacy of control of Fusarium and resultant post-treatment seed germination after use of common chemical sterilants for conifer seed and chemicals now used to sterilize seed in agricultural and micropropagation work. We also evaluated the efficacy of microwave treatments to reduce or eliminate Fusarium from seed coats.

MATERIALS AND METHODS

For both the chemical and microwave treatments, a northern Idaho source of Douglas-fir seed with known levels of seedborne Fusarium (James and others 1987) was used.

The chemical treatments consisted of six cleaning techniques (table 1), including the control (treatment 6). The control consisted of rinsing the seeds 48 hours in running tap water. Half of the seed was treated prior to cold stratification and the remainder treated after stratification. After half of the seed was treated,

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[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Intermountain Nursery Association and Forest Nursery Association of British Columbia. [Vernon, British Columbia, Aug. 8-11, 1988].

[2]Idaho Forest Wildlife and Range Experiment Station Contribution No. 405.

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all seed was rinsed for 48 hours in a running tap water wash to ensure complete imbibition before stratification. For each treatment, seeds were placed into mesh bags to facilitate handling. These were suspended and sealed inside large plastic bags. The plastic bags were then hung inside a cooler and maintained at 2° C for 21 days. After stratification, the remaining seed was treated and all seed was rinsed 24 hours in a running tap water wash.

Table 1. Descriptions of chemical treatments used on Douglas-fir seeds.

Treatment	Description[1]
1	Soaked seeds in 95% ethanol for 10 seconds followed by a running tap water rinse.
2	Soaked seeds 10 minutes in a 2.1% sodium hypochlorite solution (2 parts commercial bleach (5.25% sodium hypochlorite) in 3 parts tap water) followed by a running tap water rinse.
3	Soaked seeds in a 3% hydrogen peroxide solution for 5 hours followed by a running tap water rinse.
4	Soaked seeds 10 minutes in a 2.1% sodium hypochlorite solution acidified with HCl to pH 6, followed by a running tap water rinse.
5	Soaked seeds in 75% (v/v) ethanol for 3 minutes, rinsed three times in tap water, and then soaked seeds in a 2.1% sodium hypochlorite solution for 10 minutes followed by a running tap water rinse.
6	Seeds rinsed for 48 hours in running tap water (control).

[1] All seed was rinsed 48 hours in running tap water prior to stratification and 24 hours after stratification.

For the microwave treatments, seeds were rinsed with running tap water for 48 hours prior to 22 days cold stratification at 3° C. Following stratification, seeds were rinsed in running tap water for 24 hours. Seeds were then placed in 300 ml distilled water within a glass beaker. The water-seed mixture was heated to varying temperatures by exposure to microwaves at the full power setting for different time periods. The microwave oven used was a Kenmore model 99701 with 1,400 watts heating power (2,450 MHz). Water temperatures were recorded before and after microwave treatments. Controls consisted of seeds placed in unheated (20° C) water. Following microwave treatments, the water was decanted and the seeds allowed to cool to room temperature before blotted dry on sterile filter paper.

Colonization of seed coats by two groups of fungi (Fusarium, and Trichoderma) was determined by aseptically placing seed on a medium selective for Fusarium (Komada 1975) following treatments. Nineteen replicates of 25 seeds (475 total) were plated on the selective medium for the chemical tests and 9 replicates of 25 seeds (225 total) for the microwave treatments. Plates were incubated at about 22° C under cool fluorescent light for 7 days after which organisms within the two groups, emerging from the seed, were tallied. Percentages of seed colonized with the two groups of organisms were calculated. Several isolates of Fusarium were grown on potato dextrose agar and carnation leaf agar for identification using the taxonomic scheme of Nelson and others (1983).

Four replicates of 100 seeds from each chemical treatment and treatment time were placed into germination trays on moistened absorbent cotton pads. Ten replicates of 15 seeds for each microwave exposure time were also placed on moistened absorbent cotton pads in petri dishes. Trays and petri dishes were incubated under 12 hours of photoperiod at 22-24° C. The containers were examined every seven days for 28 days to determine germination capacity. Seed was considered to be germinated when the radicle was as long as the seed coat.

Treatment effects on germination and the occurrence of seedcoat organisms were evaluated using a one-way analysis of variance. Significant differences among chemical treatment means were located with Duncan's new multiple range test. Tukey's multiple-range comparison test was used for analyzing the microwave treatments. All data underwent arc-sin transformation prior to analysis.

RESULTS AND DISCUSSION

The chemical treatments significantly affected the cumulative germination of the Douglas-fir seed (table 2). Germination percentages for seed treated prior to stratification (all treatments combined) were significantly lower than germination percentages for seed treated after stratification. Pre-stratification use of treatments 1 and 5 gave large fluctuations in cumulative germination percentage, often 25 to 40 percent differences between replications. Both of these treatments involved ethanol. Perhaps, for seed treated prior to stratification, and especially those treatments with ethanol, seed moisture content may have an influence. Because the seed have very low moisture contents prior to stratification, they may readily imbibe the solution carrying the chemical, resulting in tissue damage and subsequently lower germination. Conversely, the seed treated after

stratification are completely imbibed and cannot readily absorb the chemical solution. Soaking the seed prior to the pre-stratification treatment may remedy this effect.

Table 2. Chemical treatment effects on the cumulative germination of Douglas-fir seed.

	Cumulative Germination at 28 Days	
Treatment[1]	Pre-stratification (%)	Post-stratification (%)
1	40 d[2]	88 ab
2	88 a	87 ab
3	51 c	92 a
4	74 b	85 b
5	54 c	84 b
6	90 a	90 ab
All treatments	66 [3]	88

[1] See table 1 for descriptions of treatments.

[2] Within each column, means followed by the same letter are not significantly different (P = 0.05) using Duncan's new multiple range test.

[3] Between pre- and post-stratification means for all treatments, the difference is significant (P = 0.01) using Duncan's new multiple range test.

In all but treatment 1, the chemical sterilants reduced seedborne Fusarium levels (table 3) when compared to the control (treatment 6). Hydrogen peroxide was the most effective chemical in reducing the levels of Fusarium on the seedcoat, supporting work by James and Genz (1981) with ponderosa pine. The combined ethanol-bleach treatment also consistently reduced Fusarium, agreeing with the work of Sauer and Burroughs (1986) on corn.

We devised a ranking procedure to determine which chemical treatment best reduced Fusarium levels, maintained high Trichoderma levels and yielded high germination percentages. In table 4, each treatment, including pre- and post-stratification applications, was given a rank according to germination percentage, Fusarium levels and Trichoderma levels. We multiplied the ranks together to obtain a score. The lowest scores received the highest ranking.

Treating the seed after stratification with hydrogen peroxide was the overall best treatment. Interestingly, our control ranked second because of its high germination capacity and the highest levels of Trichoderma. Treating seed prior to

Table 3. Chemical treatment effects on the occurrence of Fusarium and Trichoderma on seedcoats of Douglas-fir.

	Percentage Seedcoat Colonization			
	Fusarium		Trichoderma	
Treatment[1]	Pre[2]	Post[3]	Pre	Post
1	6.6 f[4]	2.1 d	82 b	30 c
2	1.6 c	4.2 e	14 d	21 d
3	0.0 a	0.2 a	28 c	52 b
4	2.8 d	0.9 c	3 f	5 f
5	0.5 b	0.9 b	5 e	10 e
6	4.5 e	5.2 f	90 a	80 a

1 See table 1 for descriptions of treatments.

2 Pre = treatments performed prior to seed stratification.

3 Post = treatments performed after seed stratification.

4 Within each column, means followed by the same letter are not significantly different (P = 0.05) using Duncan's new multiple range test.

stratification with hydrogen peroxide ranked third because of its complete eradication of Fusarium, but its negative impact on germination reduces its appeal as a treatment. Treating seed prior to stratification with bleach ranked fourth, reducing Fusarium levels by 67%. Post-stratification treatment of seed with 95% ethanol for 10 seconds reduced Fusarium levels by 57% but retained nearly twice the amount of Trichoderma as the bleach treatment. In viewing the data, hydrogen peroxide, applied after stratification, bleach, applied before stratification, and the ethanol quick dip were the three treatments that significantly reduced Fusarium while maintaining the highest germination percentages.

All chemical treatments, and the microwave treatment, were also effective in significantly reducing the levels of Trichoderma on seedcoats (tables 3 and 5). Since Trichoderma are common antagonists against Fusarium spp. (Papavizas 1985), reducing their occurrence on seed may not be desirable. This is especially true if Fusarium inoculum is introduced into containerized seedlings from sources other than seed, such as containers (James 1987, James and others 1988a) or soil mixes (James 1985b).

Effects of microwave hot water treatments on seed germination and Fusarium and Trichoderma levels on Douglas-fir seedcoats are summarized in table 5. No seed germinated after 120 seconds of exposure (66.5^{o}+ C), although germination was not significantly reduced by exposures of 90 seconds

Table 4. Rank of treatment efficacy based on cumulative germination and *Fusarium* and *Trichoderma* levels.

Treatment[1]	Cumulative germination		*Fusarium* levels		*Trichoderma* levels		Overall ranking computation	
	percent[2]	rank	percent	rank	percent	rank	formula	rank
1 pre	40 f	11	6.6 i	11	82 b	2	(11*11*2) = 242	8
1 post	88 abc	4	2.1 e	7	30 d	5	(4*7*5) = 140	5
2 pre	88 abc	3	1.6 e	6	14 g	7	(3*6*7) = 126	4
2 post	87 bc	5	4.2 g	9	21 f	6	(5*9*6) = 270	9
3 pre	51 e	10	0.0 a	1	28 e	4	(10*1*4) = 40	3
3 post	92 a	1	0.2 b	2	52 c	3	(1*2*3) = 6	1
4 pre	74 d	8	2.8 f	8	3 j	11	(8*8*11) = 704	11
4 post	85 bc	6	0.9 d	4	5 i	9	(6*4*9) = 216	6
5 pre	54 e	9	0.5 c	3	5 i	10	(9*3*10) = 270	9
5 post	84 c	7	0.9 d	4	10 h	8	(7*4*8) = 224	7
6	90 ab	2	4.8 h	10	85 a	1	(2*10*1) = 20	2

1 See table 1 for descriptions of treatments. Pre = treatments performed prior to seed stratification. Post = treatments performed after seed stratification.

2 Within the percent columns, means followed by the same letter are not significantly different (P = 0.05) using Duncan's Multiple Range Comparison Test.

Table 5. Effects of microwave hot water treatments on occurrence of *Fusarium* and *Trichoderma* on Douglas-fir seed, and cumulative germination percentage of Douglas-fir seed[1].

Exposure time (sec.)	Max. water temperature (degrees C)	Seeds with *Fusarium* (%)	Seeds with *Trichoderma* (%)	28-day cumulative germination (%)
0	20.0	3.1 a[2]	98.2 a	90 a
60	43.0	1.8 ab	96.9 a	87 a
90	55.5	0.4 b	46.7 b	86 a
120	66.5	0.0 b	0.4 c	0 b
150	77.0	0.0 b	0.4 c	0 b
180	88.5	0.0 b	0.0 c	0 b

1 See James and others (1988b).

2 Within each column, means followed by the same letter are not significantly different (P = 0.05) using Tukey's multiple-range comparison test.

(55.5° C) or less. Unfortunately, the exposure time needed to eliminate all Fusarium from seed also eliminated seed viability. However, the 90 second treatment reduced Fusarium levels to almost negligible amounts (0.4 percent) and did not significantly reduce seed germination. Treatments somewhere between 60 and 90 seconds (43° and 55.5° C) may be best for practical applications. Additional tests are necessary to locate this thermal "window" more precisely.

Treatments of agricultural seeds using vegetable oils, such as sunflower, soybean and maize oils as the medium for heat treatment instead of water, have been effective (Ryndji and others 1987, Zinnen and Sinclair 1982). The major advantage of vegetable oils over water is reduced seed imbibition of the heated medium and resulting toxicity to the embryo. There is currently no information available as to the responses of conifer seeds to such treatments, but evaluations may be beneficial because of the toxicity of hot water to Douglas-fir seed.

It is probable that other conifer species, and also other Douglas-fir seedlots, will respond differently to the chemical and hot water treatments. Larger quantities of seed treated at one time may also react differently. Additional tests are required to establish safe guidelines.

CONCLUSIONS

Sterilizing Douglas-fir seed before stratification, except with bleach, had a negative impact on germination. Conversely, seed sterilized after stratification maintained high germination percentages. Treating seed prior to stratification with bleach, after stratification with hydrogen peroxide or ethanol, or after stratification in hot water (55.5° C) significantly reduced seedborne Fusarium and Trichoderma levels while maintaining high cumulative germination.

MANAGEMENT IMPLICATIONS

We need to develop a method for rapid identification of pathogenic Fusarium. Knowing whether the seedborne inoculum is pathogenic or not would help the nursery manager decide if a seed coat sterilization treatment is necessary.

Because of this uncertainty, problems with seed from unknown collection sources, and favorable operational results, the University of Idaho Forest Research Nursery uses the bleach treatment before stratification to reduce seedborne Fusarium levels on pine and Douglas-fir seeds (Wenny and Dumroese 1987). However, for research where nearly complete eradication of Fusarium is essential (i.e. pathogenicity tests), the after stratification hydrogen peroxide treatment appears best. Growers with the benefit of sowing vigorously germinating seedlots with very low levels of seedborne inoculum are probably better off not reducing their seedborne levels of antaganistic Trichoderma with a seed sterilization treatment.

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Douglas-fir Dieback[1]

Lynn D. Husted[2]

Abstract.--Dieback of container Douglas-fir germinants is caused by a minor root pathogen. The incidence and severity of dieback are strongly influenced by (1) germinant susceptibility to the pathogen, highest the first few weeks after germination, and by (2) the growing environment, particularly moisture content, temperature and pH of the growing mix.

INTRODUCTION

For the past five years, nursery growers have observed a growth problem, termed needle dieback, in container-grown Douglas-fir seedlings. Dieback occurs in patches throughout Douglas-fir seedlots and may result in cull losses of 0-25% depending upon the nursery, sowing date and year. Dieback symptoms including stunted shoot growth, needle chlorosis, and dieback of needles from the tips to the bases. These symptoms are first noticed when the seedlings are a few centimetres tall. The root systems of dieback seedlings appear normal, exhibiting none of the external symptoms associated with root diseases.

This poster summarizes the results of Douglas-fir dieback research funded by the Canada-British Columbia Forest Resource Development Agreement. For more information, a file report is available from Dr. J. Sutherland, Pacific Forestry Centre, Canadian Forestry Service, Victoria, B.C., Canada.

RESULTS

Douglas-fir dieback is caused by a minor root pathogen. However, the incidence and severity of dieback damage depends on the growing environment and the susceptibility of Douglas-fir germinants to the pathogen (fig. 1).

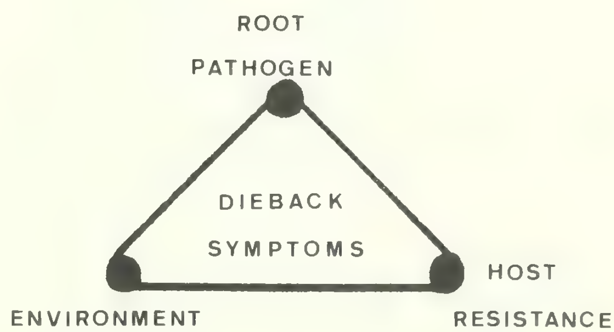

Figure 1.--Douglas-fir dieback as a minor root pathogen x host x environment interaction.

Minor Root Pathogen

A minor root pathogen, probably *Pythium ultimum*[3], causes dieback in Douglas-fir germinants. This conclusion is based on the following observations.

(1) Autoclaving growing medium or drenching it with a systemic fungicide, fosetyl aluminum, eliminates or significantly reduces the incidence of dieback.

(2) *Pythium* has been isolated consistently from surface-sterilized roots of dieback seedlings.

(3) *Pythium* oospores isolated from dieback seedling roots were cultured and used to inoculate sterile Douglas-fir seeds sown into autoclaved peat:vermiculite (PV) growing mix. *Pythium*-inoculated seedlings developed dieback symptoms. No dieback symptoms developed on control seedlings which were inoculated with heat-killed Pythium cultures. Microscopic examination of *Pythium* oospores isolated from inoculated dieback seedlings showed that they were similar to those of the original inoculum cultures.

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[1]Poster presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association Meeting (Vernon, B.C., Canada, August 8-11, 1988).

[2]Lynn D. Husted is a contract research scientist for Canadian Pacific Forest Products Limited, Victoria, B.C., Canada.

[3]Identified by Dr. H. Hartmann, M.B. Research and Development, Sidney, B.C., Canada.

(4) There are numerous reports of subclinical damage caused by a variety of *Pythium* species (Hodges 1985, Horshman 1986, Kobriger and Hagedorn 1984). Subclinical damage is characterized by stunting and growth losses in plants which have normal-appearing roots with no external symptoms of root rot.

Minor root pathogens, such as *Pythium*, are generally restricted to juvenile root tissues such as root hairs, root tips or cortical cells (Salt 1979). In Douglas-fir germinants, *Pythium* seriously reduces root hair development (figs. 2 and 3). Damage to root hairs is easily overlooked and may be of a temporary nature because root hairs may live only a few hours, days or weeks (Kramer and Kozlowski 1979). However, root hairs can comprise 50% of the total root surface area of a seedling (Kozlowski and Scholtes 1948) and therefore, contribute significantly to water and nutrient absorption.

Environment and Host Susceptibility

The degree of damage caused by minor root pathogens typically depends on the growing environment and host plant vigor (Salt 1979). Seedling age, growing mix temperature, moisture content and acidity (pH) are important factors influencing the incidence of Douglas-fir dieback in container nurseries.

Seedling Age

Percent germination is not affected by the presence of the dieback pathogen. Dieback symptoms appear two to three weeks after germination. Susceptibility to dieback decreases as seedlings age. One-week-old germinants transplanted into growing medium containing the dieback pathogen are very susceptible to the disease; 80-90% will exhibit dieback symptoms. In contrast, eight-week-old seedlings transplanted into growing mix containing the dieback pathogen do not develop dieback symptoms.

Figure 2.--Micrographs of root hair development in a healthy Douglas-fir germinant.

Figure 3.--Micrographs of root hair development in a dieback Douglas-fir germinant.

Growing Mix Temperature and Moisture

Moisture stress and high root-zone temperatures appeared to influence the incidence and severity of dieback in container nurseries. In order to determine the effects of growing mix temperature and moisture on dieback incidence, Douglas-fir germinants were transplanted into sterilized PV or sterilized PV inoculated with the dieback pathogen. The germinants were grown at two root-zone temperatures (20 and 30°C) and at three levels of moisture stress: (1) none [moisture content (MC) of medium 575%], (2) light (MC of medium 375%), and (3) moderate (MC of medium 140%).

Three weeks after germination, all seedlings grown in the sterilized PV with no inoculum appeared healthy. In the sterilized PV containing the dieback pathogen, the incidence of dieback increased with growing mix temperature and moisture stress (figs. 4 and 5). Root-zone temperature also affected the severity of dieback symptoms. At 20°C, dieback seedlings were stunted and had needle dieback; at 30°C, most dieback seedlings died.

Growing Mix pH

Douglas-fir seed was sown into 3:1 mixtures of peat:vermiculite adjusted with dolomite lime to initial pH values of 4.0, 5.0, or 6.0. During the six week experiment, pH rose 0.8 to 1.0 units in each mix. All mixes contained micronutrients. The development of dieback symptoms was strongly influenced by the initial pH of the growing mix. Mean dieback incidences (three replicates) for pH 4.0, 5.0 and 6.0 were 94%, 10% and 4%, respectively.

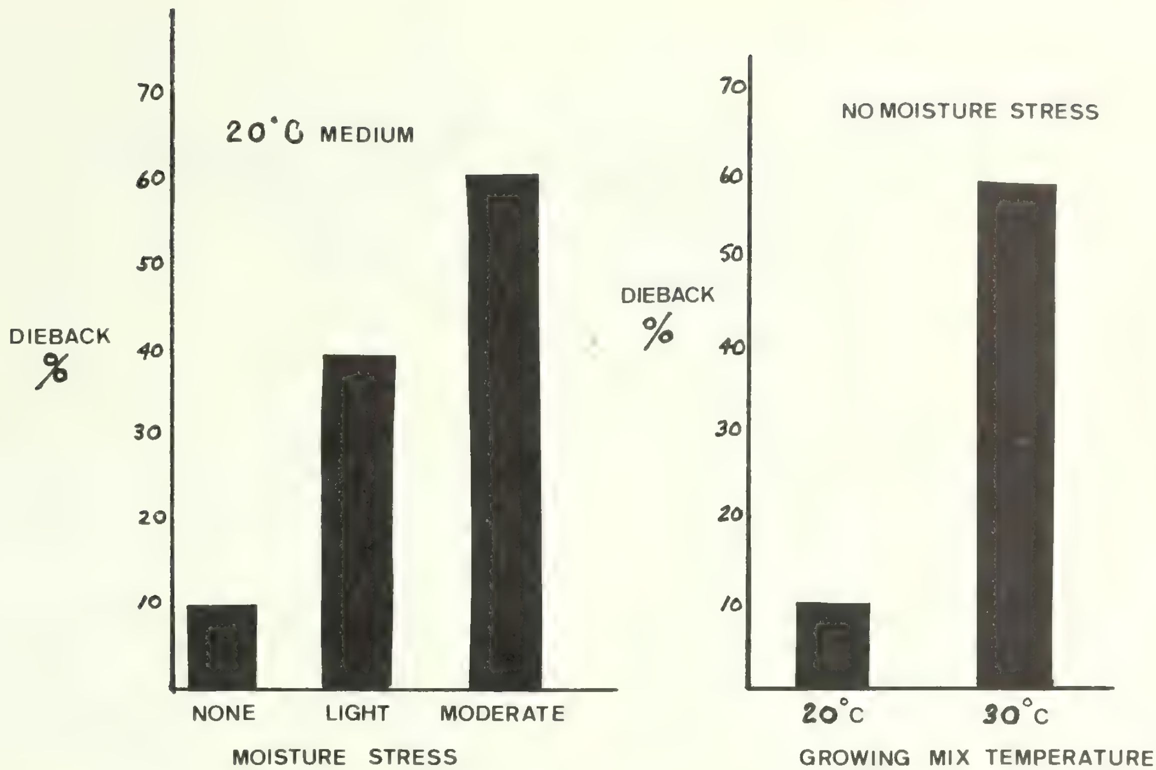

Figure 4.--Effects of growing mix temperature and moisture content on the incidence of Douglas-fir dieback.

In B.C. nurseries, a growing mix pH of 4.0 is not unusual during the first few weeks after sowing[4]. Low pH is associated with low calcium availability. Either of these factors may increase dieback incidence by (1) decreasing host vigor, or (2) decreasing bacterial competition for nutrients. Elad and Chet (1987) reported that the presence of bacteria along the roots of susceptible host plants reduced the establishment of *Pythium* along the roots; the bacteria appear to compete successfully with *Pythium* for nutrients. Low availability of calcium may also favor the germination of *Pythium* spores (Kao and Ko 1986, Qian and Johnson 1987).

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Update on the Environmental Impact Statement for Pest Management at the Federal Nurseries in the Pacific Northwest Region[1]

Sally J. Campbell[2]

The Nursery Environmental Impact Statement (EIS) is a document which will present an analysis of the environmental impacts of managing weeds, diseases, insects, and animal damage at the Wind River Nursery, Bend Nursery, Dorena Tree Improvement Center, and the J. Herbert Stone Nursery in the Pacific Northwest Region. The issues which will drive the analysis are human health, environmental quality, and economics. Several alternatives for nursery pest management will be compared and a preferred alternative will be selected upon completion of the document. The alternatives are:

1. Current pest management with the use of herbicides (situation as it existed before the 1984 herbicide ban).
2. Current pest management without the use of herbicides (situation as it existed after the 1984 herbicide ban).
3. Pest management with no chemical pesticides, Biological and cultural control methods used within the framework of a formal decision-making process.
4. Pest management using chemical pesticides as a last option after other methods have failed, within the framework of a formal decision-making process.
5. Integrated pest management using all methods, within the framework of a formal decision-making process.

The document will be completed by March 1989, and implementation of the preferred alternative will begin in 1989 at all of the Pacific Northwest Federal nurseries.

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[1]Poster presented at Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; Vernon, British Columbia, August 8-11, 1988.

[2]Sally J. Campbell, Plant Pathologist, USDA Forest Service, Portland, Oregon.

Greenhouse Transplants for Bareroot Stock Production[1]

Robert A. Klapprat[2]

Abstract.--The propagation of tree seedlings at very dense spacing in greenhouses, then transplanted with an automatic transplanter into nursery beds, has become an operational method of producing forest regeneration stock at the Thunder Bay Forest Nursery. This system optimizes; reliability, production capacity, seed utilization, stock quality and operating efficiency

The stock requested by clients of the Thunder Bay Forest Nursery is mainly the black spruce species and the transplant stock type. Its production is a two phase process; the seedling phase and the transplant phase. It has been the seedling stage that has presented extraordinary production challenges at this Nursery.

When black spruce seed is sown directly into the soils of the Nursery many elements and conditions over which we have little or no control immediately begin to work against the successful production of that crop. Even some of the precautions taken to alleviate a particular threat can have detrimental effects as well. Some of these concerns include;
seed placement which can be: too shallow, too deep, too close together or delayed,
soil erosion which can result from: wind (saltation, rain (wash-out and compaction), run-off (wash-out), irrigation (wash-out and compaction),
hydro mulch which can be restrictive to emergence
shading which can impede surveillance restrict or limit applications, destroy seedlings from frame legs, create drip-lines from wires, restrict machine manoeverability,
hand weeding which can cause trampling uprooting seedlings with the weeds, and compaction,
pre-emergent and post-emergent herbicides can be somewhat toxic to tree seedlings,
insects can cause deformity and mortality from feeding,
diseases such as damping-off and snow mould can cause deformity and mortality,
birds can cause deformity and mortality from their feeding,
traffic from people and machines can cause compaction, trampling, deformity and mortality,
weather conditions may retard germination and growth, can cause frost killing and frost heaving and flooding can cause destruction and mortality.

All of these elements are not constant. They do not have the same impact each year. During some years the combined impact may be significantly greater than in other years. Though our long term records indicate the necessity to place up to 12 seeds in the ground for each tree shipped, the fluctuations in any one year can cause drastic detractions from our reliability in achieving targets. It is this concern which prompted us to move toward a more controlled method of producing transplants; hence greenhouse transplants.

Reliability in meeting targets is achieved by more successfully nurturing germinating seeds to become surviving trees. The use of seed is optimized since each seed is placed in a micro-environment that is conducive to growth hence a greater survival percentage can be expected. Production costs are reduced as the very slow and costly processes of harvesting, grading, sorting and packaging seedlings for transplanting, and transplanting with semi-mechanical equipment are eliminated. Stock quality is improved as the stresses induced from root pruning, exposure time and nutrient depletion during transplanting as well as deformities resulting from the planting processes and frost heaving are eliminated. The production capacity of the Nursery is increased as the rotation period is reduced to two years and as compartments formerly used as seed beds can now be transplants. Harvesting costs are expected to be reduced from resulting uniformity as bed-run harvests become a reality and bulk

[1]Paper presented at the 1988 Conference, Western Forest Nursery Council Forest Nursery Association of British Columbia (Vernon Recreation Complex Auditorium, August 8-11, 1988).

[2]Robert A. Klapprat is Superintendent of The Thunder Bay Forest Nursery, Ontario Ministry of Natural Resources, Thunder Bay, Ontario, P7C 4T9 Canada.

shipments are accepted.

The decision to proceed with the Techniculture system is the culmination of many tests, trials and investigations on container types and handling systems over several years. Different products had different advantages to offer for the various stages in the production process. But the one that pulled it all together from our point of view was the Techniculture system as developed by Castle & Cooke of California. Some of the considerations which made the system particularly attractive to us include:

The medium is ready to use:
There is no necessity to purchase several components such as peat, vermiculite, perlite, wetting agents, etc., which must be accurately blended and mixed in special mixing vats. Also avoided are the filling lines and warehousing requirements of alternate soil medium and tray choices.

Greenhouse space optimized;
Each tray has 400 cavities. A typical 9.2 x 42.7 meter greenhouse will hold approximately 1.2 MM trees in a single crop. With three crops per year, one house will produce 3.6 MM trees.

The design and configuration are culturally correct;
The plug shape can accommodate the tap root of coniferous seedlings. The indentation/cavity within the plug permits ideal seed placement for even germination and growth.

The system lends itself to mechanization;
Since plugs retain their conformity they can be handled mechanically. The square dimensions of the trays permit easier alignment at all stages of production and handling.

The concept is a "system;
All components are readily available to assemble a system: trays, seeder, benching, handling, transplanting.

USING THE TECHNICULTURE SYSTEM

Central to the Techniculture system is the stabilized growing medium. It is a dimensionally stable mix of peat moss and a non-toxic binder. This medium is formed in tapered cavities which are 1.27 cm x 4.45 cm. Each resultant plug has a formed indentation which is 3.2 cm in diameter and 8 mm in depth. There are 400 plugs in each tray which has dimensions of 32.1 x 32.1 x 3.8 cm.

When trays are received from the plant in California they are already filled with the rooting medium. They usually arrive via tractor trailer and are packed on plastic wrapped pallets. The medium is moist from the manufacturing process and it is best kept that way since the plugs contract as they dry. Though trays are usually used within a short time of their arrival, we have on occasion stored them for several months without any fungal growth on their surface or any other deterioration in quality. Until recently we have discarded empty trays after use as it was not economical to return them to California. With the large quantities we are using now it is possible to make up a full load of reusable trays thus creating a back-haul for the carrier and making their return economically worthwhile.

Upon receipt at the Nursery, the trays are covered with a thin layer of the medium. This is a result of the filling process. It is actually beneficial in holding plugs from falling out prior to seeding. At seeding time this layer of material is removed with a wide putty knife. For the seeding process, a template with funnel shaped holes is placed over the tray and seeds are dropped into the cavities by the Vancouver Bio-Machine seeder. After seeding, the trays are moved by conveyor to the greenhouses where they are placed on a benching system made of Y-bar. This support system allows trays to be slid along the sides of the greenhouse. This also eases the handling during the thinning and removal processes. It takes about 14 hours to seed and fill one greenhouse.

Immediately after filling the greenhouse, irrigation begins. Frequent misting promotes rapid and even germination which, for black spruce takes 7-10 days. Because each seed is placed in an identical micro-environment, that is, a cavity which is 8 mm in depth and 3.2 mm in diameter with no mulch covering, germination and growth is usually very uniform. This is particularly beneficial in a crop like spruce which has tremendous genetic variability.

As soon as germination is complete and the seed caps are dropped and before lateral roots begin to develop, the crop is thinned. It is important that the stocking is reduced to one seedling per cavity since multiple seedlings per plug would result in multiples after transplanting and would not be acceptable for shipment after harvesting. This is a laborious time consuming operation which we hope to eliminate through more accurate seed placement and improved seed quality.

By the time thinning is completed lateral roots begin to develop and fertilizer is applied in solution with irrigation water. We begin with a "starter" fertilizer (11-41-8) at 50 ppm for 2 weeks, then switch to "grower" fertilizer (20-8-20) at 100 ppm N for the active growing period and finally a "finisher" fertilizer (8-20-30) at 40 ppm N during the conditioning period.

Three crops are grown in the greenhouses each year. The spring crop is grown from mid-March until late May/early June after which it is taken directly to the Nursery for transplanting. As the greenhouse is vacated of this crop the second crop is seeded and placed in the greenhouse. Dormancy is induced in that crop by July 31 and it is moved to outdoor holding areas by mid-August when the third crop is seeded and placed in the greenhouse. Dormancy is induced by mid-October and temperatures

are reduced in the greenhouse in order to promote hardiness in the crop.

Frost hardiness is monitored after November 1, so that the crop can be transferred to cold storage after there have been two successive weeks of freezing tests with index of injury of 5% or less at -10°C.

For overwinter storage, the trays are placed vertically in boxes which are poly sealed and placed on pallets. The storage temperature is held at -2°C until removal for transplanting the following May.

Stock is removed from the frozen storage a day or two before transplanting to permit the plugs to thaw. They are then given a good watering prior to transferring to the field for transplanting.

For subsequent transport and handling trays are placed in large cartridges. This permits easy transport to the field by truck and handling with a fork lift. The cartridges are placed on carrying platforms on the transplanter and the transplanting operation can commence.

The transplanter is a diesel powered, self propelled four wheel hydrostatically driven short turning carrier unit which supports eight high speed planting heads that can extract and transplant trees from trays that are inserted into the mechanism from the two large cartridges by two operators.

The field speed of the machine can be up to 2.0 kilometers per hour and it has a capacity of planting from 160-180 thousand trees per hour. As comparison the Holland transplanter moves at about 3-3.5 meters per minute and can plant about 15 thousand trees per hour. As already indicated, the overwintered crops are planted in a dormant condition in May and the current crop is planted in an active condition in June when the danger of frost is passed.

The transplanted stock is grown in the fields of the bare root nursery for two years prior to harvesting for shipment for plantation establishment.

Production Aspects of Mini-Plug Transplants[1]

Stephen M. Hee, Thomas S. Stevens, and Douglas C. Walch[2]

Abstract.--The MINI-PLUG™ transplant system allows the production of high quality Douglas fir transplants within a period of one or one and a half years. This patented system which was originally developed for the vegetable industry has been adapted for forestry by Weyerhaeuser Company under an exclusive use agreement from Grower's Transplanting, Inc. Along with reduced production time, this system offers substantial labor savings through the use of a highly automated transplanting machine. The paper describes the production aspects of this system.

INTRODUCTION

In 1983 Weyerhaeuser Company of Tacoma, Washington teamed up with Grower's Transplanting, Inc. (GTI) of Salinas, California to adapt GTI's automatic vegetable transplanting system to the production of forest seedlings. Our vision at that time was to be able to produce a Douglas fir seedling capable of high survival rates within one growing season and do this at a cost which would be competitive with other classes of seedlings. This paper describes our progress to date relative to the production aspects of this new type of seedling. Field performance results which have been highly satisfactory are reported by Tanaka elsewhere in these proceedings (Tanaka, 1988). Weyerhaeuser Company currently holds exclusive rights to use this patented system in all forestry applications.

GREENHOUSE PHASE

The MINI-PLUG™ production cycle utilizes both the controlled greenhouse environment and the natural climate of the bareroot nursery to produce a vigorous, hardy transplant in one year. Figure 1 outlines several growth cycles for MINI-PLUG™ transplants. Seedlings for the standard cycle are sown into the greenhouse in January and transplanted into the nursery in May of the same year. These seedlings will be ready for lifting the following winter. A second cycle which produces a MINI-PLUG™ transplant in 1.5 years can be initiated by sowing during early summer and transplanting in the fall. Combining the winter sow and summer sow cycles gives the greenhouse the opportunity for double cropping.

Producing a high percentage of fully rooted seedlings is a primary focus during the greenhouse phase of MINI-PLUG™ production. It is important that the root matrix of the seedlings hold their integrity during the transplant process because the plugs are punched out the bottom of the growing tray by a spear shaped probe. To allow the plants to be set directly into the ground, the tray is specially designed with an open bottom. The tray is also designed to serve as a magazine for the plugs so that a whole tray of plants is loaded at a time (Branch 1986).

The 26.5 inch by 6.75 inch tray has 256 cells which are approximately 1 cubic inch per cell. Because of this relatively small volume, it is important to fully fill each cell with growing medium so that no air pockets exist. To accomplish this goal, we designed and modified a tray filler which fills the cells in a stepwise fashion. Empty trays are placed on a conveyor holding a series of three bins containing peat. As the trays pass underneath each bin a layer of peat drops into the trays. Immediately following each bin, a specially designed packing wheel with cogs rotate into the cells compressing the peat as the tray passes underneath. One wheel is necessary for each row of cells. The progressive sequence of filling and compressing results in a uniformly filled tray which will enable the development of a fully extractable root system.

[1]Paper presented at the joint symposium of Western Nursery Council and Forest Nursery Association of British Columbia held at Vernon, B.C., Canada, August 9-11, 1988.

[2]Authors are respectively, Manager - Western Nurseries, Nursery Technologist and Greenhouse Technologist for Weyerhaeuser Company, Rochester, Washington.

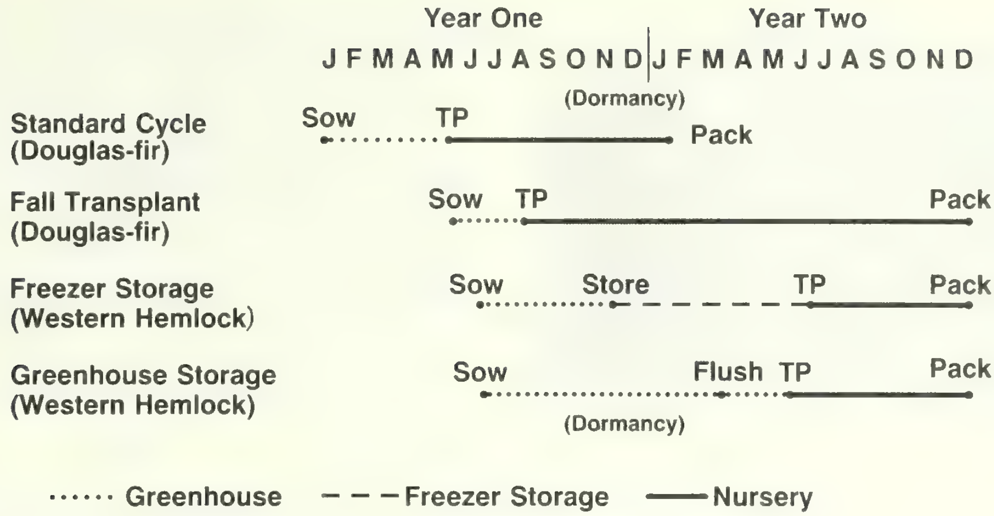

Figure 1.--MINI-PLUG™ transplant production cycles.

To facilitate air pruning of the roots, the trays are supported by extruded aluminum supports which are mounted on top of the growing beds. The beds are enclosed on all sides and warm air is pumped in below to provide heat. The trays are thus warmed by the rising heat.

Once the seedlings have completed their development in the greenhouse they are ready to be transported to the nursery. Full trays of plants are loaded into plywood bins. Each bin holds six trays and the bins are stacked onto pallets which hold nine bins per pallet. The palletized bin system will hold 54 trays or 13,824 seedlings. The pallets may be moved with a pallet jack or a forklift. The palletized system provides a transport unit which can be placed directly on the transplanter.

BAREROOT PHASE

Palletized bins of MINI-PLUG™ starters arriving from the greenhouse operation are directly loaded onto the transplanter using a forklift. The pallets are placed on an aluminum roller conveyor, which allows them to be easily moved into place. The transplanter is currently designed to hold three banded pallets or approximately 42,000 MINI-PLUG™ starters.

The basic transplanter crew consists of a tractor driver, tray handler, and transplanter operator. One or two additional people follow the machine and replant poorly placed seedlings. These crew members can also assist in the loading of the transplanter at the ends of beds.

The transplanter is 3-point mounted on an 80-horsepower tractor (fig. 2). The MINI-PLUG™ starters are pneumatically planted; consequently, two 10-horsepower air compressors are required. These compressors are mounted on the front of the tractor and they are driven by the tractor engine (Branch 1987).

Each patented seedling starter tray acts as a magazine; therefore, 256 seedling cells are loaded into the machine at one time. One side of the starter tray is notched between each starter cell. These notches are used by an indexing cylinder to feed the tray through the transplanter. The indexing cylinder cycles 80-90 times per minute and with each cycle eight air driven plant setters spear a MINI-PLUG™ starter cell. While holding the seedlings vertical, the setter spears push the starter cells through the bottomless trays into the furrows created by the shoes. Water is injected into the furrow just ahead of the actual planting of the MINI-PLUG™ starters. The MINI-PLUG™ starters are held vertically by the setter spears, while the furrow shoes continue to move forward and soil is packed around the cells. The setter spears then retract and both the trays and setters return to position over the shoes, ready to plant another complement of eight seedlings (figs. 3-6). A unique feature of this machine is that during the planting process the carriage holding the trays and setters moves backwards at the same speed the tractor is moving forward. Thus, the MINI-PLUG™ starters are planted at zero relative ground speed, resulting in high quality planting. The empty trays are indexed out of the machine, flipped 90 degrees on side and conveyed back to the tray loader for placement into an empty bin (Branch 1987).

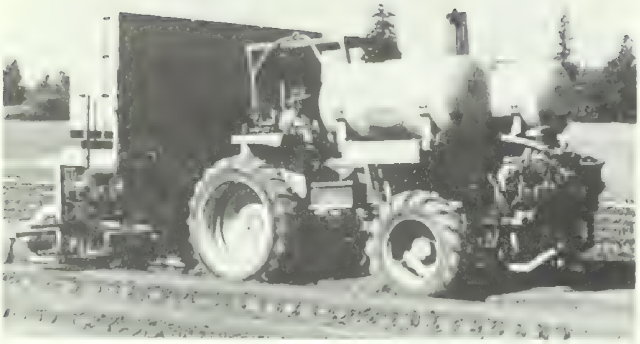

Figure 2.--MINI-PLUG™ tranplanter and tractor.

Precise adjustment of the planter mechanism to the surface of the transplant beds is required as the MINI-PLUG™ starters are only about 1 inch in length. To accomplish this, hydraulic cylinders were installed in the link arms of the three point hitch to provide side to side adjustment and a hydraulic cylinder was mounted on the ski frame at the rear to give fore and aft trim. The controls for this bed trim system are mounted at the rear of the transplanter to allow quick and precise adjustment by the machine operator. In contrast, most transplanters are manually adjusted or hydraulically adjusted by the tractor operator, who is in a poor position to judge bed conditions and planting quality.

During transplanting, water can be injected into each furrow just prior to the planting of the MINI-PLUG™ starter cells. The water system consists of twin two hundred gallon water tanks mounted on the tractor and a hydraulically driven tube pump located on the transplanter. The quantity of water flowing into the furrows is adjusted depending on soil moisture and weather conditions. This water system eliminates the need for immediate irrigation to reduce transplanting shock. Thus, soil preparation and transplanting activities are not interrupted by irrigation.

Once transplanted in the bareroot nursery, the MINI-PLUG™ transplants are culturally treated similar to other transplant crops. These seedlings are lifted and shipped to the field after one growing season in the bareroot nursery. Upon lifting, these seedlings exhibit a dense mop-like root system having a profusion of lateral roots. Though somewhat more compact than other seedlings, MINI-PLUG™ transplants have an excellent shoot to root ratio (table 1).

SUMMARY

MINI-PLUG™ transplants have excellent shoot to root ratios, which result in high survival and growth rates. In the field high outplanting production rates are possible because of their compact size and mop-like root system. The MINI-PLUG™ transplant system requires a shorter production cycle (1-1.5 years) than other transplant stock types (2-3 years). A higher level of growing space utilization can be achieved as less space is required in both the greenhouse (2218 starters/sq meter) and the nursery (113 transplants/sq meter) than other transplant stock types. Because of the short greenhouse growth cycle more than one crop per year may be grown in the greenhouse. The MINI-PLUG™ transplanting system is highly automated with the capability of transplanting 40,000 MINI-PLUG™ starters per hour. Transplant shock is reduced because the MINI-PLUG™ starters are provided with in-furrow watering as part of the transplanting process. Transplanting costs are less as a result of a lower labor requirement; and total seedling costs per thousand can be further reduced by the increased stocking level in the nursery beds.

Table 1.--Morphological comparison of different stock types from 1988 tests.

Stock Type	Height (cm)	Caliper (mm)	Shoot/Root Ratio (Dry Weight)
[1]MPT-S	20.6	4.3	1.67
[2]MPT-F	47.0	7.6	
2+0	37.0	5.4	2.94
1+1	52.2	6.9	2.86
2+1	51 9	7.4	2.33

[1]MPT-S Spring Transplanted Mini-Plug™ Transplant

[2]MPT-F Fall Transplanted Mini-Plug™ Transplant

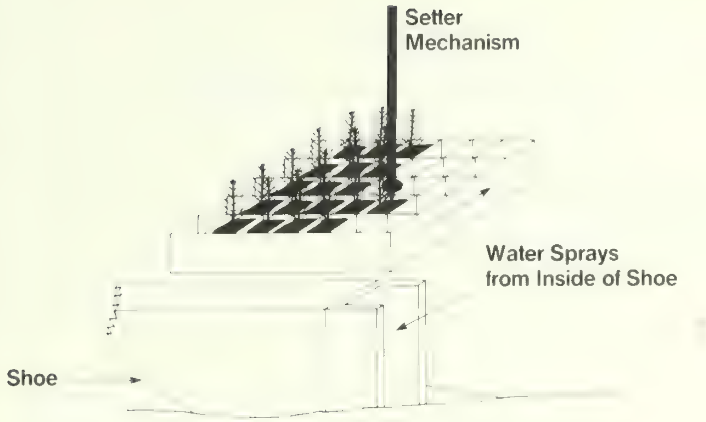

Figure 3.--Tray has just indexed to position new starter cell under setter mechanism.

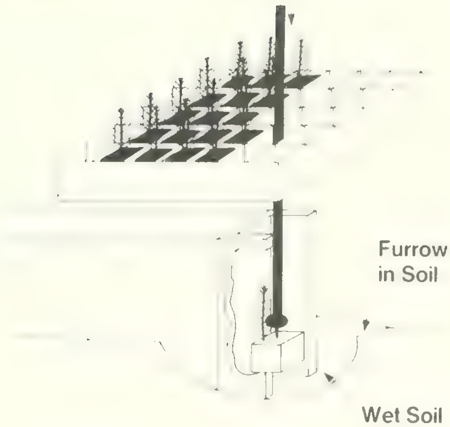

Figure 4.--Spear extends into starter cell to hold it vertical while cell is pushed through tray into furrow behind shoe.

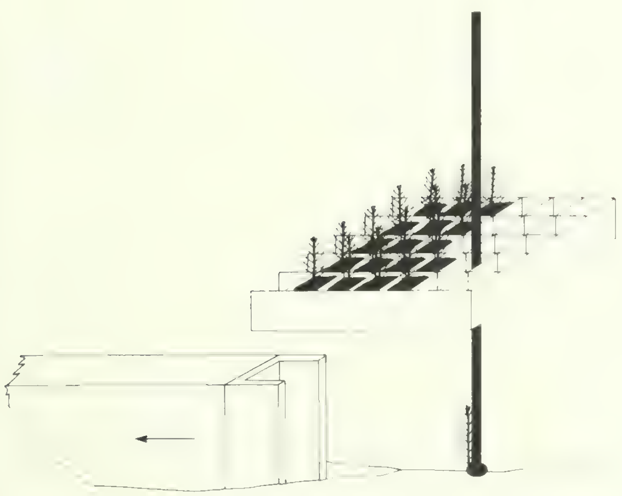

Figure 5.--Spear holds starter cell upright as shoe moves forward and soil closes around cell.

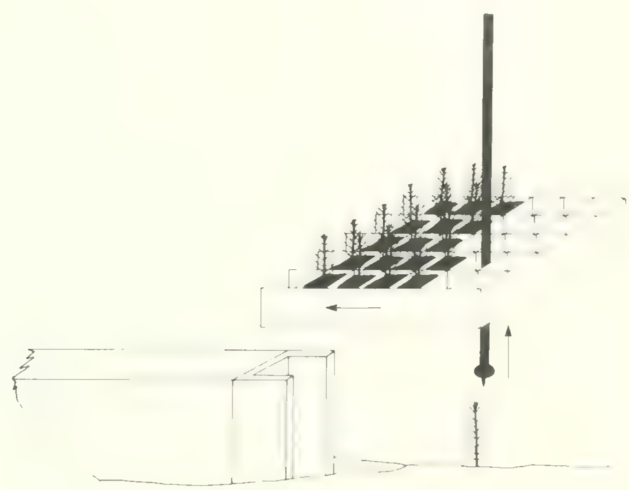

Figure 6.--Mini-Plug™ starter has been planted, spear retracts and setter mechanism returns to position over the shoe for the next cycle.

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Field Performance of Mini-Plug Transplants[1]

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Abstract.--A new stock type, mini-plug™ transplant (MPT), has been developed at Weyerhaeuser Company. MPT's are started in the greenhouse and transplanted into the nursery where they are grown for one season. Advantages of using MPT's are (1) short production time to improve flexibility of regeneration planning, (2) ease of planting due to compact mop-like root system and (3) relatively low production costs. A total of 68 trials to evaluate Douglas-fir MPT's were installed at six regions in Washington and Oregon in 1985, 1986 and 1987. Survival, vigor, damage and height growth were measured annually. The results showed that probably owing to favorable root to shoot ratio and fibrous roots, MPT's performed as well as or better than other bareroot stock types including 2+0's, low density 2+0's, 1+1's, plug+1's and 2+1's at a majority of sites. MPT's put on the same amount of height growth or greater than the other stock types. Furthermore, MPT's appreciably exceeded the other stock types on a relative growth rate based on the original height. However, MPT's had less total height than other stock types due to its smaller initial height. There appeared to be no preference of MPT's over other stock types in terms of frequency of big-game browsing and rabbit clipping. But, because of their smaller size, MPT's were unable to withstand heavy animal damage as well as larger stock types.

INTRODUCTION

A new method of producing planting stock called "mini-plug™ transplant (MPT)" has been adapted from the agricultural transplant industry for forestry by Steve Hee and his nursery staff, Weyerhaeuser Timberland Division (Hee, et al., 1988). Mini-plug™ starter crops are sown in December into trays with cavities about one cubic inch in volume. They are grown for 5-6 months in the greenhouse under an extended daylength. Actively growing starter plants, 4-5 inches in height, are then transplanted into the nursery beds by machine around May and grown for one season before outplanting.

There are a number of advantages to using MPT's. First, they take only one year to grow and thus increase flexibility of regeneration planning. Second, they are potentially inexpensive as compared with other types of transplants including 1+1's, 2+1's and plug+1's because of short production time, greater growing density and a high degree of mechanization. Third, they have a compact fibrous root system and are easy to plant in the field.

To determine the field performance potential of Douglas-fir MPT's, we installed a total of 68 field trials at six geographic regions in Washington and Oregon and have been monitoring their performance in comparison with other stock types in these trials annually. The present paper reports our observations to date.

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[1]Paper presented at the 1988 Western Nursery Council at Vernon, British Columbia, August 8-11, 1988.

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MATERIALS AND METHODS

Field performance of MPT's was compared with that of 2+0's, low density 2+0's, plug+1's, 1+1's and 2+1's of Douglas-fir at the following six Weyerhaeuser western regions: Cascade, Chehalis, Twin Harbors, Longview regions in Washington and Springfield and Coos Bay regions in Oregon. At each region, three types of trials were installed: (1) stock comparison tests (SCT), (2) field performance trials (FPT) and (3) region block plantings (RBP).

All the stock used in this study were produced at one of three Weyerhaeuser barreoot nurseries: Aurora located near Portland, Oregon; Mima near Olympia, Washington; and Turner near Salem, Oregon. MPT starter plants were grown at the Company's greenhouse in Rochester, Washington and subsequently transplanted into the nursery beds at Aurora and Mima. In the 1985 trials, MPT's and 2+0's stock were from both Aurora and Mima while 1+1's and 2+1's stock were from Aurora and Mima, respectively. In the 1986 and 1987 trials, all the stock tested at the Washington regions were from Mima while those tested at the Oregon regions were from Aurora. The only exceptions were the stock outplanted at the Longview region in 1986, when MPT's were from Aurora, 2+1's from Aurora (SCT) and Turner (FPT's and RBP), 1+1's from Aurora and 2+0's from Mima.

The SCT was a replicated row planting of several stock types and followed a randomized block design. It consisted of 100 trees/stock type (four blocks x 25 trees in 1985 trials and five blocks x 20 trees in 1986 trials). The approximate distance between rows was three feet and distance between trees within a row was two feet. All the stock types operationally used at a given region were included in the SCT at that region so the number of stock types varied from one region to the other. The SCT was enclosed by a fence and was protected from animal damage pressure in order to study maximum survival and growth potential. The fence was specially installed for the 1985 SCT's while progeny test sites with existing fences were used for the 1986 SCT's.

The FPT was also a replicated row planting with the same spacing between rows and trees within a row as SCT. It was a completely randomized design with four blocks each with 25 trees for a total of 100 trees/stock type. The two major differences between SCT and FPT were that (1) the FPT was not enclosed by a fence and was subject to animal damage pressure and (2) the FPT generally compared the performance of MPT's with that of one or two other stock types operationally used at the site where the FPT was located.

The RBP was a larger scale trial consisting of two 3-6 acre blocks. One block represented MPT's and the second block the other stock type operationally used in that area. Trees were planted with operational spacing of 10 x 10 feet. The trial was replicated two to three times in the 1987 installations in Chehalis, Twin Harbors and Longview. Special emphasis was placed in selection of sites so that two stock types were tested under uniform environments.

We installed a total of 68 trials during the 1985, 1986 and 1987 period. A breakdown of installations by types of trials at each region is shown in Table 1. A breakdown is also shown according to the year of installation in Table 2. Study sites used for these trials are shown in Table 3 by region and year of installation. The names of sites are accompanied by the method of site preparation in parenthesis -- burned (B), scarified (S) or no site preparation (N).

All the trials were installed at the beginning of each installation year and trees were assessed for vigor, survival, type and location of damage and height in the fall of each year following installation. Vigor, survival and damage were also assessed in early summer in many of the trials. Assessments were made on all the trees in SCT's and FPT's. In RBP's, permanent transects encompassing all areas of blocks were established and about 100 tagged trees were monitored in each stock type.

Trees were classified into one of five vigor classes using the following Weyerhaeuser western forestry seedling assessment code.

Vigor Classes	Vigor Category	Description
1	High	Green needles, no loss of foliage
2	High	Green needles, 75%+ foliage retention
3	Medium	Some chlorosis, 50%+ foliage retention
4	Low	Chlorotic, dying
5	Dead	Brown stem and foliage

Table 1.--Number of trials installed in each of three trial types at six regions in Washington and Oregon.

Region	SCT[1]	FPT[2]	RBP[3]	Total
Cascade	1	6	6	13
Chehalis	1	4	5	10
Twin Harbors	1	4	6	11
Longview	2	6	3	11
Springfield	4	10	0	14
Coos Bay	1	8	0	9

[1] Stock comparison test.

[2] Field performance trial.

[3] Region block planting.

Table 2.--Number of trials installed in each of three years at six regions in Washington and Oregon.

Region	1985	1986	1987	Total
Cascade	1	9	3	13
Chehalis	0	7	3	10
Twin Harbors	0	8	3	11
Longview	1	6	4	11
Springfield	2	6	6	14
Coos Bay	0	5	4	9
Total	4	41	23	68

Table 3.--Study sites used for MPT trials at 6 regions in 1985-1987.

Region	Year of Installation	Sites
Cascade	1985	Bald Hills (B)[1]
"	1986	Boyles Lake (N), Carnation (N), Deer Creek (S), Bayne Junction (N)
"	"	Orting Lake (N), Bald Hills (B), 3950 Road (N)
"	"	Kings Lake (N), Rhodes Lake (N)
"	1987	Barr Hill (N), Highrock (N), Greenwater (N)
Chehalis	1986	Garrard Creek (S), Bloomquist (B), Deer Creek (B and N)
"	1987	Ceres Hill (N), Deer Creek (B and N)
Twin Harbors	1986	Church Road (B), Wishkaw (N), Mayors Brother (B) Delezenne (B), Fall River (N)
"	1987	Satsop (B), Hippi Camp (N), Wiekswood (B)
Longview	1985	Mt. Brynion (B)
"	1986	Finkas (B), 1390 Road (N), 4534 Road (N), 0020 Road (B), 0518 Road (B), Tower Road (B)
"	1987	4830 Road (B), 1890 Road (B), Sucker Creek (S)
Springfield	1985	5330 Road (B), 5540 Road (B)
"	1986	Wendling (S), Shoestring (S), 3330 Road (B) 5180 Road (S), 114 Road (N), 9300 Road (B)
"	1987	7010 Road (N), 1060 Road (S), 6260 Road (B), 410 Road (B), 2340 Road (B), 5305 Road (N)
Coos Bay	1986	3394 Road (S), 8300 Road (N), 8312 Road (S)
"	1987	9120 Road (S), 9100 Road (N), 3360 Road (N), 3367 Road (N)

[1] Notations between parenthesis show methods of site preparation:

(B) - Burning (S) - Scarification (N) - None

The data was analyzed using analyses of variance procedure (Steel and Torrie, 1960). Percentage values were transformed into arcsin $\sqrt{\%}$ prior to analyses. In comparing three or more stock types, if F values were significant at the 5% risk level, the treatment differences were tested using Duncan's new multiple range test.

Because of a large amount of data from all the assessments, in the present paper we'll be only reporting selected pertinent information predominantly from the fall 1987 assessment, focusing on total survival, percent of trees with high and medium vigors and animal damage of all trials. Yearly changes of total height in 1985 and 1986 SCT are also reported.

RESULTS

Survival and Vigor

1985 Trial:

MPT's from Mima and Aurora exhibited excellent survival, 96% and 94%, respectively at Mt. Brynion, Longview after three growing seasons in the field (Table 4). Survival of Mima MPT's was significantly higher than that of 2+0's from Mima (78%) and Aurora (83%). The 2+1's from Mima showed an intermediate survival of 87%.

Table 4.--Survival of four stock types after three growing seasons in 1985 trials at four sites

Stock Type	Nursery	Mt Brynion[1]	Bald Hills[2]	5330 Road[3]	5540 Road[3]
MPT	Mima	96 a[4]	73 a	79 a	70 a
MPT	Aurora	94 ab	75 a	80 a	65 b
2+0	Mima	78 b	35 b	-	-
2+0	Aurora	83 b	56 ab	-	
2+1	Mima	87 ab	31 b		
1+1	Aurora	-	-	81 a	96 a

[1] Longview region, assessed in the fall of 1987

[2] Cascade region, assessed in the fall of 1987.

[3] Springfield region, survival after two growing seasons assessed in the fall of 1986

[4] Means followed by the same letters within each column are not significantly (p < .05) different

At Bald Hills, Cascade, overall survival was lower than at Mt. Brynion due to harsh conditions of southern exposure and shallow soils. The survival trend, however, was the same as Mt. Brynion with MPT's from Mima (73%) and Aurora (75%) outperforming 2+0's from Mima (35%) and Aurora (56%) and 2+1's from Mima (31%).

At 5330 Road, Springfield where the field condition was also harsh (southern exposure) overall survival was also lower than at Mt. Brynion. MPT's from Mima (79%) and Aurora (80%) showed a similar level of survival as did 1+1's from Aurora (81%).

At 5540 Road, a milder site with northern exposure, survival of MPT from Mima (70%) and Aurora (65%) was greatly reduced as compared with 1+1's (96%). The survival difference was significant between Aurora MPT's and 1+1's. The reduction was mainly due to browsing by a deer which had entered the fenced area, becoming trapped and causing damage for an extended period of time. The larger 1+1's were able to withstand the browsing more than the MPT's.

1986 Trial:

Cascade -- MPT's performed as well as 2+1's, low density 2+0's, plug+1's and 2+1's at all FPT's except at Bayne Junction (Figure 1). Percent of MPT's with high and medium vigor was substantially reduced at this site due to rabbit clipping in the first year and big-game browsing in the second year.

As in the 1985 trial, survival of MPT's (76%) and 2+0's (68%) stock was substantially lower at Bald Hills due to harsh conditions. Although not significant, percent of trees with high and medium vigor was greater for MPT's (72%) than for 2+0's (53%).

In RBP's, survival of MPT's was significantly higher than that of 2+0's (99% vs. 85%) and low density 2+0's stock (96% vs. 87%) at Rhodes Lake and Kings Lake, respectively. At 3950 Road, both MPT's (97%) and plug+1's (94%) showed an equally high survival.

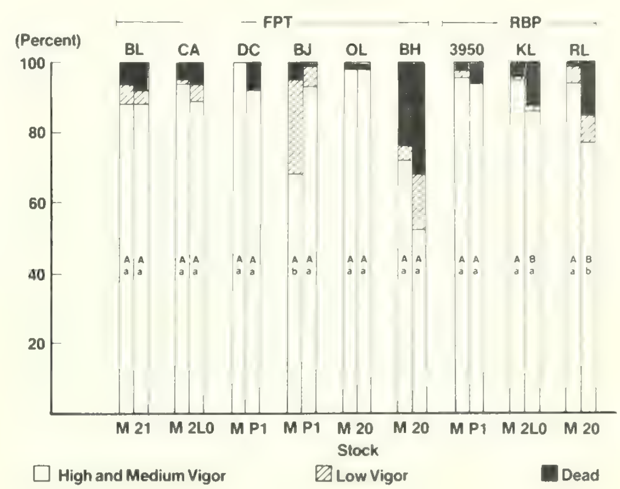

Figure 1.--Survival and vigor of mini-plug™ transplant (M) compared with those of low density 2+0 (2LO), plug+1 (P1) or 2+0 (20) in 1986 trials after two growing seasons at Cascade region, Washington: BL = Boyles Lake, CA = Carnation, DC = Deer Creek, BJ = Bayne Junction, OL = Orting Lake, BH = Bald Hills, 3950 = 3950 Road, KL = Kings Lake, RL = Rhodes Lake. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

Chehalis -- In SCT's and FPT's, MPT's showed high survival rates of over 90% and did as well as 2+0's, 2+1's, 1+1's or plug+1's at all sites (Figure 2). In the RBP's, plug+1's survived significantly better than MPT's (96% vs. 82%) at Deer Creek burned site while an opposite trend was observed at Deer Creek which received no site prep. (82% vs. 89%, not significant).

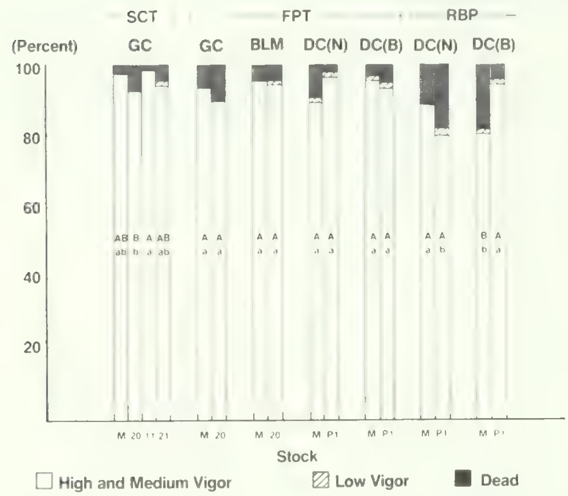

Figure 2.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+0 (20), 1+1 (11), 2+1 (21) or plug+1 (P1) in 1986 trials after two growing seasons at Chehalis region, Washington: GC = Garrard Creek, BLM = Bloomquist, DC(N) = Deer Creek, no site preparation, DC(B) = Deer Creek, burned. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and in high and medium vigor (small letter).

Twin Harbors -- Survival of MPT's and plug+1's was substantially reduced (to less than 75%) at Delezenne FPT and RBP (Figure 3). Although the difference in survival or percent of trees with high and medium vigor was not significant, the impact of the damage tended to be greater for the smaller MPT's. Survival of MPT's was also significantly reduced by big-game browsing as compared with 2+0's (61% vs 91%) at Fall River RBP. MPT's performed equally well or better than other stock types where animal damage pressure was low.

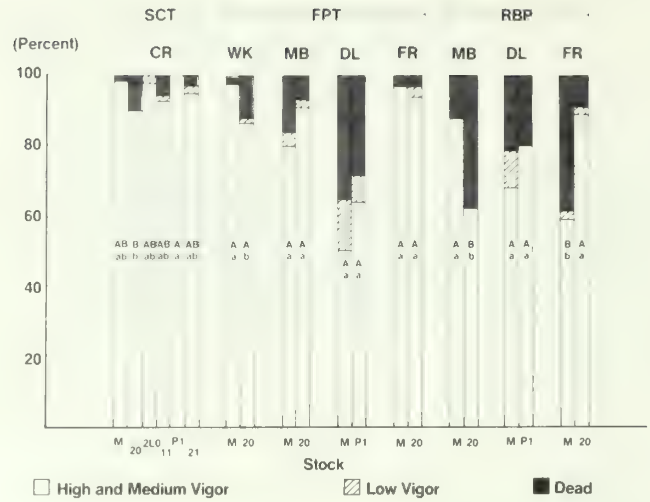

Figure 3.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+0 (20), low density 2+0 (2LO), 1+1 (11), plug+1 (P1) or 2+1 (21) in 1986 trials after two growing seasons at Twin Harbors region, Washington: CR = Church Road, WK = Wishkaw, MB = Mayor Brother, DL = Delezenne, FR = Fall River. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

Longview -- MPT's generally had lower survival (75%-87%) at this region than at Cascade, Chehalis and Twin Harbors (Figure 4). Poorer performance is attributed to unusually severe winter damage from freezing and desiccation while in the nursery beds at Aurora. Many lots of transplants from Aurora showed less than normal survival in 1986. In contrast, 2+1's stock from Turner, which did not suffer winter injury, showed high survival rates of mostly over 90%. The difference between survival of MPT's and 2+1's was significant at 1390 Road FPT (95% vs 77%) and at 4534 Road FPT (95% vs. 75%). At Finkas SCT, however, MPT's survived as well as 2+1's or 1+1's from the same nursery. Damage caused by big-game browsing significantly reduced the percent of trees with high and medium vigor as compared with 2+1's (29% vs. 85%) at Tower Road RBP.

Oregon -- As in Longview, overall survival of MPT's, 1+1's and 2+0's stock was relatively low and variable at Springfield (Figure 5) and at Coos Bay (Figure 6) due to the winter nursery damage. MPT's survived as well as 1+1's and 2+0's stock at eight out of 11 trials in these regions.

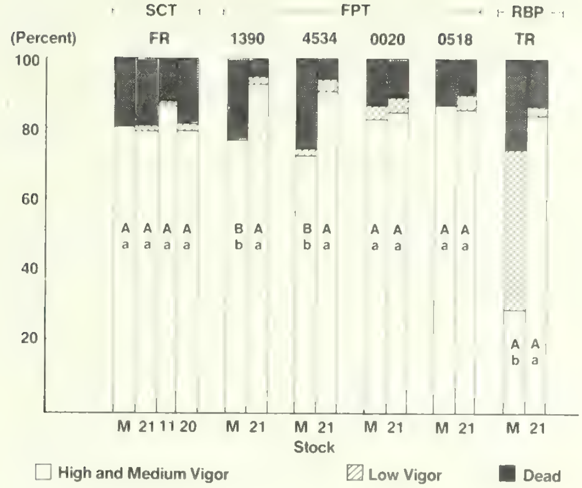

Figure 4.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+1 (21), 1+1 (11), or 2+0 (20) in 1986 trials after two growing seasons at Longview region, Washington: FR = Finkas road, 1390 = 1390 Road, 4534 = 4534 Road, 0020 = 0020 Road, 0518 = 0518 Road, TR = Tower Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

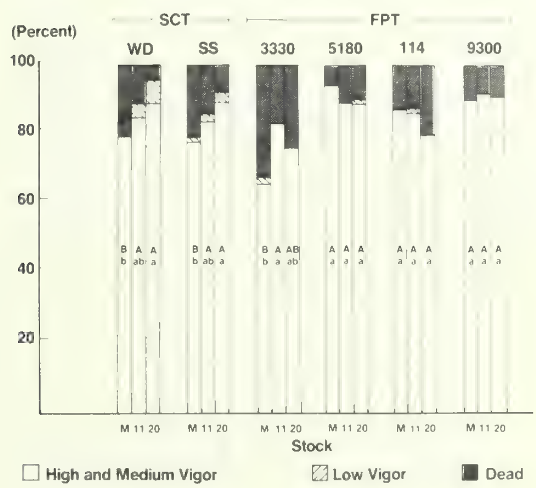

Figure 5.--Survival and vigor of mini-plug™ transplant (M) compared with 1+1 (11) or 2+0 (20) in 1986 trials after two growing seasons at Springfield region, Oregon: WD = Wendling, SS = Shoestring, 3330 = 3330 Road, 5180 = 5180 Road, 114 = 114 Road, 9300 = 9300 Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

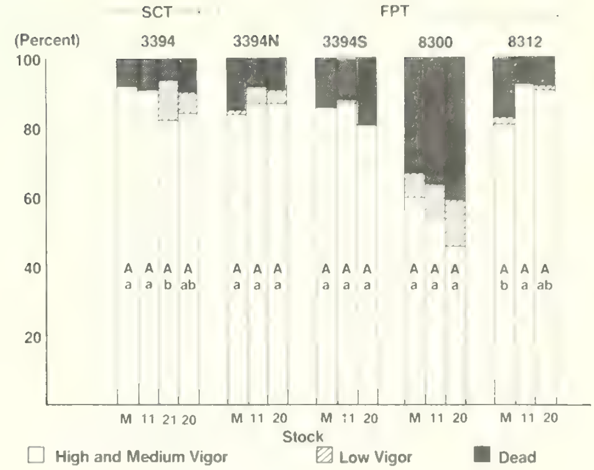

Figure 6.--Survival and vigor of mini-plug™ transplant (M) compared with those of 1+1 (11), 2+1 (21), or 2+0 (20) in 1986 trials after two growing seasons at Coos Bay region, Oregon: 3394S = 3394 Road south-facing slope, 8300 = 8300 Road, 8312 = 8312 Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

1987 Trial:

Cascade -- MPT's performed as well as 1+1's stock at Barr Hill and Greenwater and slightly better than low density 2+0's stock at Highrock (Figure 7).

Chehalis and Twin Harbors -- The frequency of animal damage was relatively high at most sites (30% - 70%). However, browsing and clipping were mostly on lateral branches and generally had no significant impact on survival after one growing season. MPT's did as well as 2+0's, 1+1's and 2+1's stock at all sites except at Deer Creek (with no site prep.) where 1+1's survived significantly better than MPT's (100% vs. 95%). (Figure 8)

Longview -- MPT's and 1+1's showed an excellent performance of survival over 95% in both FPT's and RBP's at all three sites (Figure 9). At Sucker Creek RBP, survival of MPT's was reduced to 79% as compared with 2+1's (92%) due to rabbit clipping; however, the difference was not significant because of the large variability within stock types.

Springfield -- All three stock types including MPT's, 1+1's and plug+1's showed excellent performance at all six FPT's sites in Springfield with survival exceeding 95% (Figure 10).

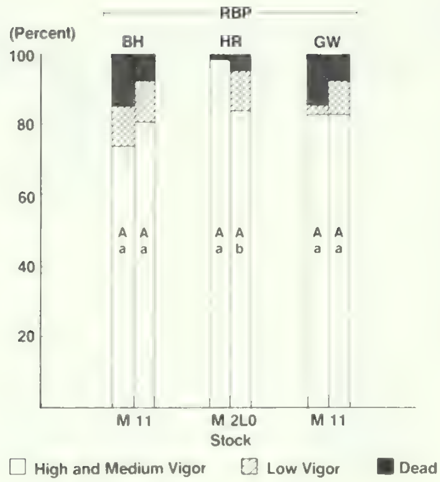

Figure 7.--Survival and vigor of mini-plug™ transplant (M) compared with those of 1+1 (11), or 2+0 (20) low density 2+0 (2LO) in 1987 trials after one growing season at Cascade region, Washington: BH = Barr Hill, HR = Highrock, GW = Greenwater. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

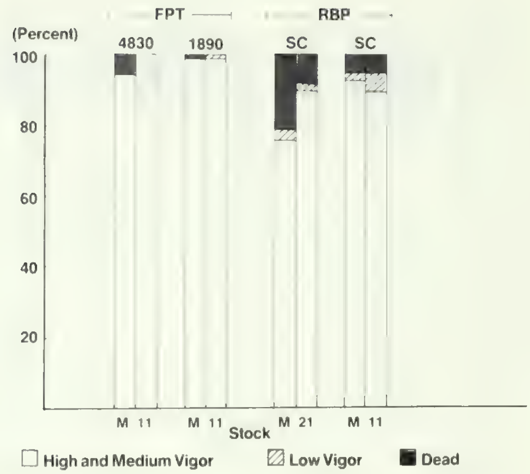

Figure 9.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or 2+1(21) in 1987 trials after one growing season at Longview region, Washington: 4830 = 4830 Road, 1890 = 1890 Road, SC = Sucker Creek. Within each site, the differences between stock types were not significant (p < .05) in total survival or in high and medium vigor.

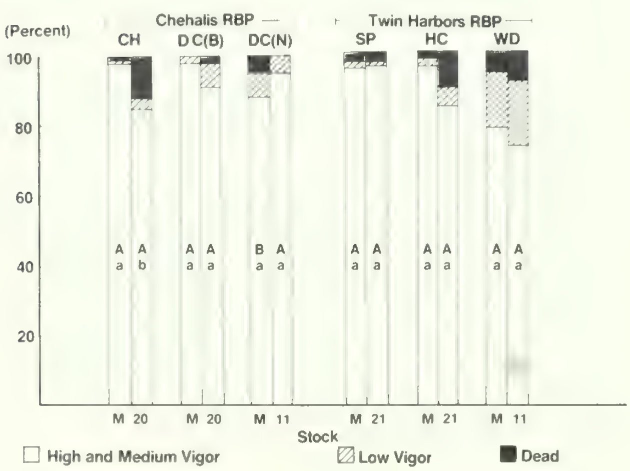

Figure 8.--Survival and vigor of mini-plug™ transplant (M) compared with 2+0(20), 1+1(11) or 2+1(21) in 1987 trials after one growing season at Chehalis and Twin Harbors regions, Washington: CH = Ceres Hill, DC(B) = Deer Creek burned site, DC(N) = Deer Creek no site preparation, SP = Satsop, HC = Hippi Camp, WD = Wiekswood. Within each site stock types followed by the same letters are not significantly (p < .05) different in total survival (capital) and high and medium vigor (small letter).

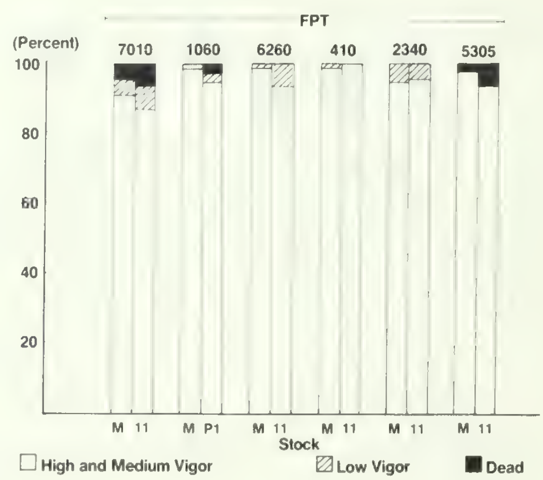

Figure 10.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or plug+1(p1) in 1987 trials after one growing season at Springfield region, Oregon: 7010 = 7010 Road, 1060 = 1060 Road, 6260 = 6260 Road, 410 = 410 Road, 2340 = 2340 Road, 5305 = 5305 Road. Within each site, the differences between stock types were not significant (p < .05) in total survival or high and medium vigor.

Coos Bay -- Overall survival was somewhat lower at Coos Bay than at Springfield (Figure 11). The 1+1's tended to perform slightly better than MPT's and 2+0's, but the differences among stock types were not significant.

HEIGHT GROWTH

Height growth of MPT's paralleled that of 2+0's and 2+1's at Mt. Brynion 1985 SCT site (Figure 12). After three growing seasons in the field, the height differences among three stock types were about the same as those at the time of outplanting.

The observations from 1986 SCT's showed that the height growth rate of MPT's was greater than that of 2+0's with both stock types attaining the same total height (73 cm) after two growing seasons in the field, although the original height of 2+0's (30 cm) was greater than that of MPT's (19 cm) (Figure 13). A similar trend was also observed in the 1986 FPT's and RBP's (unpublished data).

The 1986 SCT's also showed that the total height after two growing seasons was greater for 2+1's (92 cm) and 1+1's (91 cm) than for MPT's. But the growth rate of MPT's was the same or slightly greater than those of 2+1's or 1+1's as evidenced by slightly smaller differences in total height between stock types after two growing seasons.

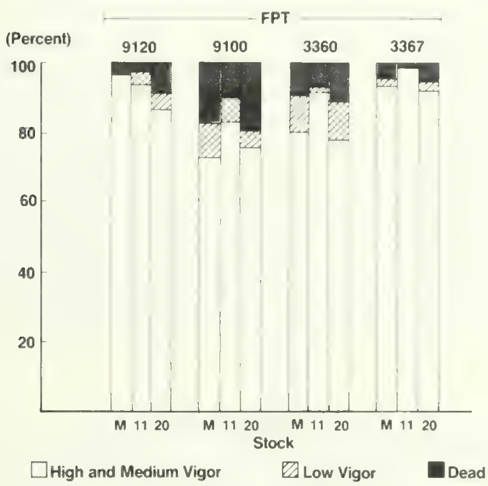

Figure 11.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or 2+0(20) in 1987 trials after one growing season at Coos Bay region, Oregon: 9120 = 9120 Road, 9100 = 9100 Road, 3360 = 3360 Road, 3367 = 3367 Road. Within each site, the differences between stock types were not significantly ($p < .05$) different in total survival or high and medium vigor.

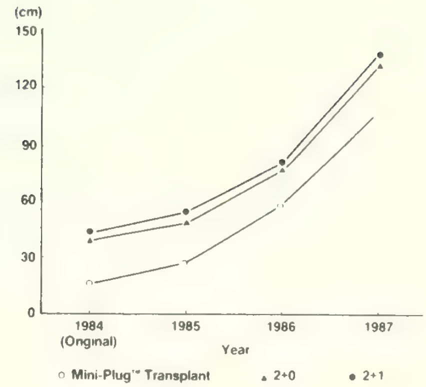

Figure 12.--Total height of three stock types at Mt. Brynion, Longview. All measurements were done in the fall of each year.

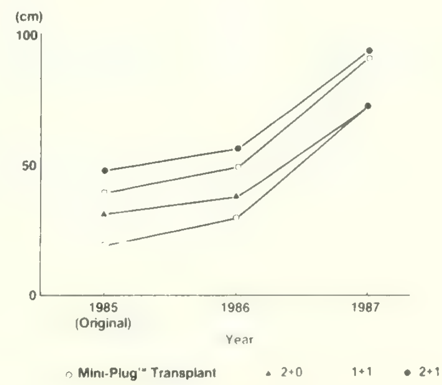

Figure 13.--Total height of three stock types. Mean of three stock comparison tests installed in 1986. All measurements were done in the fall of each year.

ANIMAL DAMAGE

The above survival and vigor data showed that the impact of animal damage was greater on MPT's than on other stock types due to their smaller original size. There was no distinct preference of MPT's over other stock types based on the frequency of animal damage in 1986 (Table 5) and 1987 (Table 6) trials, the browsing just caused more damage to the smaller MPT's.

With respect to site preparation, animal damage of MPT's tended to be greater on burned sites than on scarified sites or sites with no preparation in both 1986 (Table 7) and 1987 (Table 8) trials.

Table 5.--Percent of animal-damaged trees by stock type during the first (1986) and second (1987) year after outplanting in 1986 FPT and RBP.

STOCK TYPE	FPT 86 (%)	FPT 87 (%)	RBP 86 (%)	RBP 87 (%)
MPT	12	17	38	21
2+0	6	16	17	18
1+1	6	21	-	-
2+1	28	20	12	-
P+1	18	25	22	12

Table 6.--Percent of animal-damaged trees by stock type during the first (1987) year after outplanting in 1987 FPT and RBP.

STOCK TYPE	FPT	RBP
	(%)	(%)
MPT	13	25
2+0	11	12
1+1	15	15
2+1	-	42
P+1	28	65

Table 7.--Percent of animal-damaged trees by site preparation during the first (1986) and second (1987) year after outplanting in 1986 FPT and RBP.

SITE PREP	FPT 86	FPT 87	RBP 86	RBP 87
	(%)	(%)	(%)	(%)
BURN	31	20	44	29
SCARIFIED	6	15	-	-
NONE	7	10	28	16

Table 8.--Percent of animal-damaged trees by site preparation during the first (1987) year after outplanting in 1987 FPT and RBP.

STOCK TYPE	FPT	RBP
	(%)	(%)
BURN	20	42
SCARIFIED	1	-
NONE	10	8

DISCUSSION

Based on survival, vigor and height growth, MPT's performed as well as or better than other bareroot stock types including 2+0's, low density 2+0's, 1+1's, plug+1's and 2+1's at a majority of sites. Superior performance of MPT's was particularly evident at a shallow, harsh site at Bald Hills, Cascade Washington, where larger 2+0's and 2+1's stock showed lower survival rates. It was also noted that MPT's do not appear to suffer from transplant shock as much as other stock types as was evidenced by their generally comparable or superior height growth over the other larger stock types. In terms of the percent of the original height, height growth of MPT's was significantly greater than that of other stock types.

Good survival and height growth of MPT's are attributed to their morphological characteristics. They have a high root to shoot (R/S) dry weight ratio and fibrous root system. Measurements of stock outplanted in 1987 showed that R/S ratio of MPT's (0.62) was greater than that of 2+0's (0.38), 1+1's (0.38), 2+1's (0.42) or plug+1's (0.47) (Table 9). The MPT's are also characterized by a mop-type fibrous root system which results from many growing tips created by air-pruning of roots near the root collar while growing in the containers (Hee _et al_ 1988).

Use of MPT's increases flexibility of reforestation planning because of their short production time of one year. Changes in logging schedules or an unexpected fire could create a need for a readily available planting stock such as MPT's. MPT's are also less costly to produce than 2+1's or plug+1's, although their production costs are currently similar to that of 1+1 because of a somewhat variable yield. We expect, however, that the cost of MPT's will be less than that of 1+1's in the near future because they require a short production time, transplanting is highly mechanized and they are grown at a higher density.

Table 9. Morphological characteristics of five stock types used in 1987 installation.

Stock type	Avg. Height	Avg. Diameter	Dry Weight Shoot	Root	R/S ratio
	(cm)	(mm)	(g)	(g)	
MPT	23	4.7	3.8	2.3	0.62
2+0	38	5.1	5.5	2.0	0.38
1+1	46	6.7	11.4	4.3	0.38
2+1	54	7.8	15.8	6.6	0.42
P+1	40	6.1	8.2	3.3	0.47

While height growth in percentage of original height was the greatest of all stock types, total height of MPT's at the end of the first, second and third year in the field was generally smaller than that of other stock types due to their smaller original size. Because of this factor, MPT's were often unable to withstand big-game browsing and rabbit clipping as well as the larger stock types especially if damage occurred prior to budbreak. Survival, vigor and growth of MPT's were significantly reduced in areas of heavy animal pressure in Twin Harbors and Longview in 1986. Further observations suggested, however, that there was no preference of MPT's over other stock types based on the frequency of animal damage.

In order to minimize such animal damage, it appears to be advantageous to use larger MPT's than the ones currently produced without compromising the root to shoot balance and fibrosity of roots. Nursery trials have been in progress with promising results. Crops started in mid-summer and subsequently (1) transplanted in fall or (2) stored in a cooler or freezer before transplanting the next May have shown larger and more uniform size than the current crop. This crop requires an additional half-year to produce but may perhaps be more desirable for use in the areas with heavy animal damage pressure.

It has been pointed out that tree planters have difficulty in maintaining spacing between trees in the field due to poor visibility of small MPT's. However, this advantage may be offset by the fact that the root system of MPT's is compact and easy to plant. This seems to be particularly true in poorly prepared sites or rocky sites where stock with a larger root system is difficult or sometimes impossible to plant.

The present study indicated that the frequency of animal damage of MPT's was greater in burned areas than in areas with no site preparation. Additional observations from specifically designed trials would be needed to ascertain this trend since the present study was not intended to test the differences of site preparation under similar field conditions. The observations, however, are in agreement with those of others (Campbell 1982). If the above trend is proven to be true it may be possible to reduce the level of animal damage by planting MPT's in areas with minimum site preparation.

ACKNOWLEDGEMENTS

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Computer Vision for Grading Tree Seedlings[1]

Michael P. Rigney and Glenn A. Kranzler[2]

A computer vision algorithm measuring several morphological characteristics of pine seedlings was developed. Singulated seedlings were inspected on a moving belt at production-line rates. Classification as acceptable or cull was based on minimum criteria for stem diameter, shoot height, and projected root area. Individual seedlings were graded in approximately 0.25 seconds. Average classification error rate was 5.7 percent.

INTRODUCTION

Hundreds of millions of tree seedlings are grown annually in commercial, federal, and state nurseries. At harvest, these seedlings are graded to remove inferior stock and improve productive potential. Advances in equipment and cultural practices leave seedling grading as the only remaining labor-intensive operation at most nurseries.

Grading is typically performed manually through application of a number of visual quality criteria. Although stock types and cultural practices vary widely among nurseries, several generalizations may be made about current grading practice. Manual inspection tends to be labor-intensive and costly. Seedling classification is subjective and susceptible to human error. Grading and sorting into multiple acceptable classes is not feasible. Valuable production data, including morphological statistics and cull rate, are difficult to obtain. Disadvantages of manual grading have spurred growing interest in automated alternatives.

Automated systems have been constructed for measurement of seedling characteristics (Buckley et al., 1978) and seedling grading (Lawyer, 1981). Mechanical and opto-electronic methods were used to successfully measure stem diameter, shoot height, and projected root area, however, neither machine could match manual grading productivity.

Digital image processing has been successfully implemented in many industrial and agricultural inspection processes. It has demonstrated high accuracy and throughput, permitting 100% inspection where product sampling was previously the only feasible method of quality control (Kranzler 1985). Machine vision inspection would appear to be an ideal tool for addressing the tree seedling grading problem.

OBJECTIVES

This study was initiated to investigate the ability of machine vision to grade bare-root pine seedlings under nursery production conditions. Specific objectives included:

1. Develop and implement a machine vision algorithm to measure key morphological characteristics and grade seedlings at production-line rates.
2. Evaluate performance in terms of measurement speed, precision, and accuracy of classification.

METHODS AND MATERIALS

Assumptions

Several assumptions were adopted concerning the environment in which commercial grading would be performed. First, seedlings would be singulated, permitting only one seedling to appear within the camera field-of-view at a given time. This requirement could be relaxed to the constraint that adjacent seedlings simply must not touch. Singulation is straightforward for container-grown seedlings, but bare-root stock requires special handling equipment (Graham and Rohrbach, 1983).

Second, loose constraint of shoot orientation (+/- 30 degrees) and lateral position (+/- 6 cm) was imposed. Orientation and position constraints simplify both hardware and software, but are not necessary for

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commercial implementation. Finally, it was assumed that a black conveyor belt would be used to transport seedlings beneath the cameras. Again, other configurations are possible, for example, acquiring images as the seedlings fall past a backlight.

Equipment

Equipment included a conveyor belt, machine vision computer, cameras, lenses, and lights. To simulate production grading operations, a variable-speed belt conveyor was constructed to transport seedlings for inspection. The shiny surface of the black belt was dulled by sanding to minimize specular reflection.

An International Robomation/Intelligence (IRI) D256 machine vision development system was used. Images were digitized into an array of 256 X 240 picture elements (pixels) with 256 grey levels of intensity. A high-speed hardware coprocessor performed computationally intensive operations such as image windowing, filtering and edge detection, runlength-encoding, and moments calculations. Software was developed in the C programming language.

Two Hitachi KP-120U solid-state black-and-white television cameras were employed for image acquisition. Camera 1 was used to obtain a close-up image of the seedling root collar zone. A field-of-view (FOV) approximately 12.8 cm (5 in) square provided a 0.5 mm (0.02 in) pixel resolution (fig.1). Camera 2, with a FOV approximately 51 cm (20 in) square and resolution of 2.2 mm, acquired an image of the entire seedling.

Illumination was provided by fluorescent room lighting and strobed xenon flash. Relatively low-level room lighting was adequate for detection of the moving seedlings in the FOV of camera 2. When a seedling was detected, synchronized strobe lamps were triggered to obtain a "frozen" image with each camera.

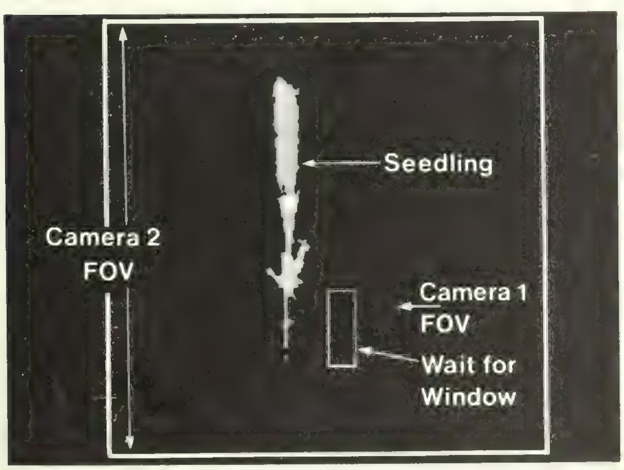

Figure 1.--Field-of-view for cameras 1 and 2. Note Waitfor window.

Grading Scheme

Morphological characteristics are used for grading most nursery stock. These characteristics include stem diameter at the root collar, shoot height and weight, root weight or volume, root fibrosity, foliage color, presence of terminal buds, shoot/root volume ratio, and ratio of top height to stem diameter (sturdiness ratio) (Forward 1982, May et al. 1982). Stem diameter, shoot height, and root volume are generally given priority and were adopted as the grading criteria for this study. Of these three, stem diameter is typically considered most important.

To meet image processing time constraints, we decided to emphasize stem diameter measurement accuracy and obtain close approximations of shoot height and of root volume as indicated by projected root area (root area index). A classification scheme based on minimum acceptable values of these three parameters (May et al. 1982) is given in table 1. Seedlings were graded into two classes; acceptable and cull.

ALGORITHM

The grading algorithm is composed of several separate tasks. These are: calibration, seedling detection, shoot orientation measurement, root collar location, diameter measurement, root area measurement, shoot height measurement, grade classification, and recording of seedling statistics. A detailed description of the algorithm is presented by Rigney (1986).

Selection of FOV for camera 1 required a compromise between diameter measurement precision and the probability of the root collar appearing within the FOV. Because the lateral position of the root collar cannot be tightly constrained, a relatively wide FOV is necessary. We decided to make the FOV as large as possible, while maintaining a measurement precision of at least 0.5 mm (0.02 in). Selecting 0.5 mm as the pixel resolution yields a 12.8 cm FOV. Measurement precision can be increased through use of a smaller FOV and more precise seedling handling or by substituting a higher resolution camera/computer system.

Seedling Detection

Under ambient lighting conditions, a sequence of images acquired with camera 2 (wide FOV) is processed as follows. Each image is masked by a template defining a window in which seedling presence is tested (Waitfor window, fig. 1). Seedling detection triggers image acquisition from each camera with strobe illumination. In the following algorithm descriptions, image 1 and image 2 refer to images acquired by camera 1 and camera 2, respectively.

Seedling Orientation

Image 2 is first processed to determine seedling orientation on the conveyor belt. Area moment calculations provide the angle between the seedling major axis and the vertical axis of figure 1.

Table 1.--Grading scheme for loblolly pine seedlings

Stem Diameter (mm)	Root Area Index (pixels)	Shoot Height (cm)	Grade
3.0 to 8.0	> 200	> 16	Acceptable
Otherwise			Cull

Subsequent measurements of stem diameter and shoot height are corrected for orientation angle. Because measurement error becomes excessive at large angles, seedlings are not graded if the orientation angle is greater than thirty degrees.

Location of the Root Collar

Accurate location of the root collar is crucial for subsequent measurement of stem diameter, shoot height, and root area index. Image 1 (small FOV) is processed by an iterative algorithm to find a collar location satisfying heuristic criteria. Consider each horizontal line in the image to be composed of pixel strings belonging either to the foreground (seedling) or background (conveyor). Further, define the frequency of a line to be the number of transitions between the foreground and background. The root collar may intuitively be expected to be located in a region of low frequency lines bounded by areas of higher frequency. Needles, branches, and roots contribute many transitions to horizontal lines in figures 2 and 3 (high frequency). Lines in the root collar zone contain significantly fewer transitions. The width of individual pixel strings is also exploited, since we have a priori knowledge of the expected stem width.

Line frequencies are processed to build a list of root collar candidates. The resulting list is processed to locate the root collar both vertically and horizontally. The algorithm will find the root collar of most seedlings in one iteration. Seedlings with branches, needles, or roots in the root collar zone require two iterations for collar location.

The scale and mapping relationship between images 1, and 2 was previously determined during system calibration. After locating the root collar in the close-up image 1 the collar location is mapped into image 2.

Measurement of Stem Diameter

Diameter measurement processing is performed inside a region around the root collar location in image 1. Region size is defined by the set of candidate collar lines found in the collar location subroutine. The region is processed with an edge detector favoring vertical edges, since we know that shoot orientation is approximately vertical. An edge detection operation yields an image of edge intensity. The average distance between the strongest edges bracketing the root collar is calculated as the collar diameter (fig. 4).

Figure 2.--Camera 1 close-up image details root collar region.

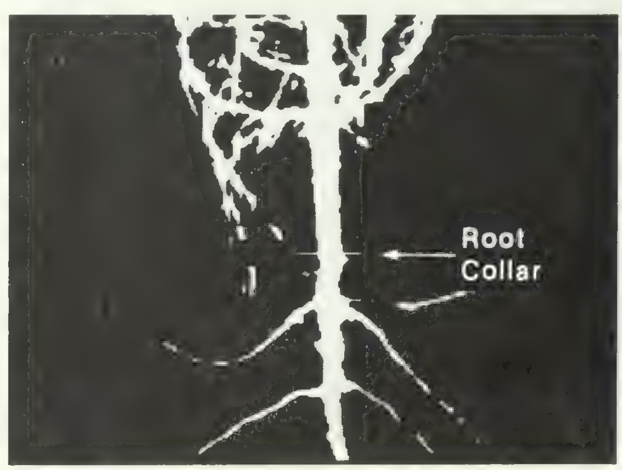

Figure 3.--Algorithm locates root collar.

Measurement of Root Area Index

Root area index is measured from that portion of image 2 below the root collar (as mapped from image 1). An edge detector sensitive to all edge orientations is applied. The weakest edges detected are the result of noise in the image background (conveyor belt). Above the noise level, however, roots much smaller than the pixel dimension (2.2 mm) can be detected because of their contribution to the brightness of a corresponding pixel. Pixels with edge intensities greater than the noise level are summed to yield projected root area (fig. 5).

Measurement of Shoot Height

Image 2 is processed to determine shoot height. Starting at the top of the image, each line is tested to determine if it has enough information to indicate the presence of the seedling top. The seedling top is assumed to be located when four consecutive lines meet this criterion. Shoot height is defined as the distance between the seedling top and root collar (previously mapped into image 2).

Measurement of Shoot Area

Projected shoot area is determined from that portion of image 2 above the root collar. Pixels with an intensity greater than the background intensity are counted to provide area. This measurement was amended to those described above to allow calculation of shoot/root area ratio.

Main Program

Inside the main program loop, values returned by subroutines are tested to control program flow. If all grading subroutines are successful in their respective tasks, a grade classification is assigned to the seedling.

Whenever a subroutine fails its task, the seedling is recorded as not gradable. Finally, measured seedling parameters, grade, and count are written to a statistics file.

Calibration

Proper calibration of threshold values and scale factors is essential for optimum algorithm performance. The calibration subroutine initializes sixteen parameters with default values. The user is then provided an opportunity to interactively alter the default values. A wooden dowel of known diameter and length is used to calibrate scale factors. Grey level thresholds are set using a representative seedling. Algorithm performance was relatively insensitive to grey level thresholds if "reasonable" values were selected. Threshold selection could be automated in a commercial implementation, eliminating operator subjectivity.

EVALUATION

A reference set of 100 loblolly pine (Pinus tacda L.) seedlings was manually measured and graded. Stem diameters ranged from 2.3 to 6.0 mm. Performance of the machine vision system was then evaluated by grading each of the seedlings twenty times. Shoot orientation was limited to plus-or-minus thirty degrees from vertical, and root collar location was constrained to the FOV of camera 1.

Time required for the algorithm to grade a seedling averaged approximately 0.25 seconds. Strobe illumination provided reliable image capture at conveyor speeds of up to 1.0 m/s (3.3 ft/s), corresponding to a grading rate exceeding three seedlings per second. To facilitate manual placement of the seedlings on the conveyor, tests were conducted at a belt velocity of 0.5 m/s (1.5 ft/s).

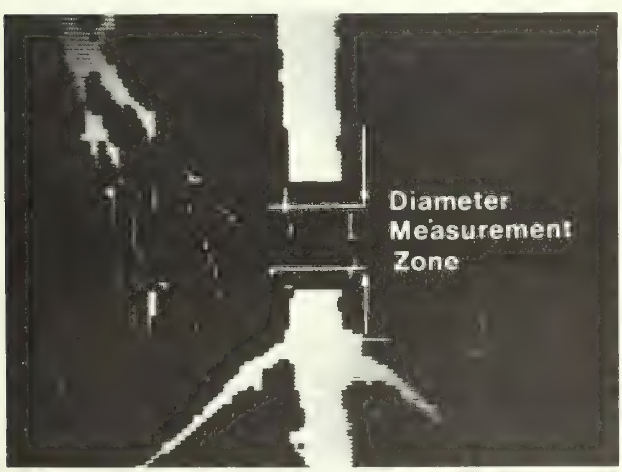

Figure 4.--Image is processed to define stem edges in root collar zone.

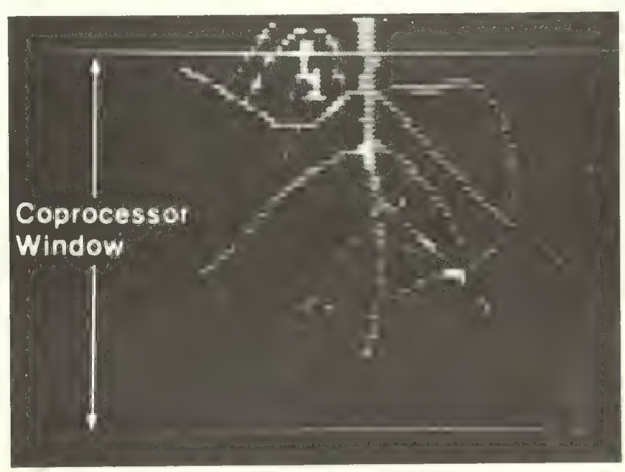

Figure 5.--Image is processed to highlight seedling roots.

Table 2.--Percent misclassification of 100 seedlings, 20 reps

Manual Grade	Acceptable		Cull		Total		
	#	mis.	#	mis.	#	mis.	n.g.
Borderline	6	31.7%	11	18.6%	17	23.2%	2.6%
Easily Classified	63	2.2%	20	2.0%	83	2.2%	2.3%
All	69	4.7%	31	7.9%	100	5.7%	2.3%

n.g. = not gradable mis. = misclassified

The classification error rate averaged 5.7 percent for the set of 100 seedlings (table 2). This is very acceptable performance, bettering manual grading operations which have an average misclassification rate of seven to ten percent (Boeckman, 1986). As expected, a large part of the classification error was attributable to seedlings which straddled the borderline between acceptable and cull, with respect to diameter and root area. Such seedlings comprised 17 percent of the grading test set and had an average misclassification rate of 23.2 percent. The remaining 83 seedlings had an average misclassification rate of 2.2 percent (table 2). Since there is no significant penalty for misclassification of borderline seedlings, 2.2 percent misclassification may be a better indicator of algorithm performance.

Measurement precision was excellent, considering the spatial resolutions of cameras 1 and 2, which were 0.5 mm/pixel and 2.2 mm/pixel respectively. The coefficient of variation of 20 measurement repetitions averaged 7.6, 12.2, and 4.1 percent for stem diameter, root area, and shoot height, respectively. This result indicates a standard deviation of 0.23 mm for a 3.0 mm stem diameter.

The few seedlings which showed the largest deviations in measured parameters were characterized either by needles extending down past the root collar, or by roots bent upward past the root collar, or both. The subroutine which located the root collar performed inconsistently on such seedlings. A few of these seedlings could not be graded.

In subsequent work, projected shoot area was measured, allowing calculation of shoot/root area ratio. Though not tested, we anticipate a correlation between projected area and mass, allowing fast and non-destructive estimation of conventional shoot/root mass ratio. Calculation of the sturdiness ratio (diameter/height) has also been implemented and could provide another parameter for classification.

The measurement precision demonstrated by the algorithm suggests use for classification of seedlings into several acceptable grades. Additional grade definitions could be optimized for specific planting sites. Further, we expect that the comprehensive statistics collected in a commercial implementation would make machine vision grading a valuable nursery management and research tool.

The research described was implemented on a 240 X 256 pixel resolution camera/computer system which was the industry standard at the time of purchase (1984). Systems with 512 X 512 pixel resolution are common today, and the trend toward increased resolution is expected to continue. New systems, with improved architectures and faster central processing units, offer an increase in measurement precision as well as reduced processing time.

The two-camera configuration used in this investigation could be replaced with a single-camera 1024 X 1024 pixel system to yield identical diameter resolution, quadruple height resolution, and 16 times the area resolution. In such a configuration, the amount of raw data (pixels) would increase by a factor of eight. A large percentage of the image would be background, however, and would not require processing.

Further work is being performed in seedling classification and measurement of container grown seedlings. Alternative decision functions, including statistical classifiers, are being investigated for improved classification performance. Plug-surface root-area measurement of container grown seedlings (after extraction) requires segmentation of the roots from the growth medium with special lighting and image processing. Verification of correct plug shape might also be of value.

SUMMARY AND CONCLUSIONS

This study has demonstrated that machine vision can provide accurate production-rate grading of harvested bare-root pine seedlings. Singulated seedlings were transported on a conveyor belt, with shoot orientation and root collar position loosely constrained. Seedlings were classified as acceptable or cull on the basis of stem diameter, shoot height, and projected root area. Tests with loblolly pine seedlings revealed excellent system performance. Seedlings were graded in approximately 0.25 seconds, with an average classification error rate of 5.7 percent. These results

exceed manual grading performance, which typically requires one second per seedling with an error rate of seven to ten percent. Misclassification was largely due to seedlings with borderline diameter and/or root area, and the occurrence of branches or roots in the root collar zone. Measurement precision was adequate for seedling classification into several grades, suitable for specific planting sites. The technology promises increases in both speed and measurement accuracy.

DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination is intended or endorsement implied.

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Effect of Nursery Treatment on Shoot Length Components of Western Hemlock Seedlings during the First Year of Field Establishment[1]

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Abstract.--The effects of nursery pretreatments, such as dormancy induction (photoperiod and moisture availability), two styroblock cavity sizes, and three dates of lifting and cold storage duration, on shoot length components were investigated in seedlings of western hemlock (Tsuga heterophylla (Raf.) Sarg.) during their first year of growth on two sites on Vancouver Island, B.C. Seedlings pretreated to short days combined with moisture stress and those lifted in November had very short shoots. Seedlings pretreated to long days and those lifted in March had the longest shoots. Because most stem units were preformed during bud development in the nursery, differences in stem unit length had a larger impact on shoot length than differences in number of stem units. Lammas growth was most frequent in seedlings from the smaller cavities and in those from the November and March lifts.

INTRODUCTION

A variety of western hemlock Tsuga heterphylla (Raf.) Sarg.) seedling stock types having different physiological and morphological characteristics can be produced by modifying nursery cultural practices (O'Reilly et al. 1989a, 1989b; Arnott et al. 1989; Grossnickle et al. 1989). A logical follow-up would be to see how different stock types perform under field conditions. To this end, we carried out a study of the phenology of flushing and shoot elongation, seedling morphology, and bud development of different seedling stock types of western hemlock growing on two adjacent sites, typical for the growing environment of the species on Vancouver Island. This paper summarizes some of the results on the effects of nursery pretreatment on shoot length components. The results of other parts of the field study will be reported elsewhere.

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MATERIALS AND METHODS

Seedling Stock Types

Western hemlock seedlings of mid-elevation (British Columbia Ministry of Forests Registered Seed Lot No. 3907; 48° 39' N, 123° 39' W, elevation, 760 m) seedlot from Vancouver Island were grown in BC/CFS styroblocks (PSB) (Beaver Plastics Ltd., Edmonton, Alta.) of small (PSB 313 abbreviated to S3) and large (PSB 415B abbreviated to S4) cavity diameters that were subjected to different dormancy induction and lift/storage treatment combinations (see Arnott et al. 1989). The seedlings were grown under 18 h day lengths until the dormancy induction treatments began. The dormancy induction treatments included short- (8 h) (SD) or long-day (18 h) (LD) photoperiods in combination with drought (D = dry) or no drought (W = wet) conditions that began in mid-July, 1986 and ended 4 weeks later. Seedlings were grown under ambient day length conditions thereafter. The final treatment included three lifting dates/cold storage duration treatments that took place in mid-November, 1986 (lift N), mid-January (lift J) and mid-March (lift M) 1987, for a total of 24 nursery treatment combinations. Seedlings

from lifts N and J were stored at 1°C in cold rooms at the Pacific Forestry Centre, Victoria until the final lift on March 18, 1987. All seedlings were transported to Nanaimo, B.C. where they were stored in a MacMillan Bloedel cold room (1°C) until planting.

Study Area

The seedlings were planted in early April, 1987 on 2 adjacent sites at the Summit Main (SR5), Franklin River Division, MacMillan Bloedel Ltd. (Lat. 48° 55' N, Long. 124° 45', elev. 675 m). This area is within the windward submontane maritime wetter CWH variant (CWHbl) as described by Green et al. (1984). One site, facing northwest (NW), is classified as wet (hygrotope 5-6, trophotope B-C (burnt)) while the other is classified as dry (hygrotope 1-2, trophotpe B-C (burnt)) and is of southeast (SE) aspect. Average slopes on these sites are about 60% and 40%, respectively.

Experimental Design

The study area was laid out according to a split-plot factorial (randomized block) design, similar to that described in Kirk (1982). Each of the 24 nursery treatment combinations was represented by two replicates per block per site. Each replicate was assigned at random to a row plot; each row contained about 25 seedlings. Seedling spacing was at 2 m within rows and 1 m between rows. One of the two replicates per block was assigned at random for destructive sampling while the other was retained as a permanent plot.

Data Collection

After shoot growth cessation in late September 1987, eight seedlings per row were sampled at random for study. A total of 1104 plants were examined; this was 48 less than planned because of seedling mortality.

Seedling shoot growth in the field in 1987 occurred through internodal elongation of stem units that originated from the overwintering bud, and from free and lammas growth. The stem units in the bud are predetermined as they were formed during nursery culture. Free growth occurred in the first season of field growth through production of new needle primordia followed by immediate internodal expansion. Lammas growth occurred through the premature flushing of the new bud that was formed in the same season. It was not possible to distinguish needles produced during free growth from those present in the overwintering bud. However, a good estimate could be made of these numbers because numbers of needle primordia in the overwintering bud were recorded at the end of the nursery experiment (O'Reilly et al. 1989b). The lammas portion of the shoot was easy to identify by the presence of bud scales on the new shoot in addition to those of the new overwintering bud. Also, some free growth commonly takes place as the lammas bud elongates; all growth distal to the lammas bud scales was considered as lammas growth despite this fact. The 1987 shoot was divided into two portions for the purpose of this study, the predetermined-free and the lammas growth sections.

The following data were recorded from the 1987 shoot of each seedling: (1) total shoot length; (2) length of lammas shoot; numbers of needles or stem units[5] (NSU) in the (3) predetermined-free (4) and lammas growth sections of shoot; and (5) numbers of bud scales at base of the lammas shoot. New variables calculated from these data included: (6) total NSU, i.e. (3) + (4) + (5); and (7) lammas NSU, i.e. (4) + (5). Stem unit length (SUL) was calculated for the (8) whole shoot and for the (9) predetermined-free and (10) lammas portions of the shoot by dividing shoot length by NSU for the appropriate portion.

Data Analysis

Data were analysed according to a modified version of the split-plot factorial (randomized block) design as outlined in Kirk (1982). The Spssx MANOVA procedure (Spssx Inc. 1986) using unique sums of squares was employed in all analyses. The error term for each factor (e.g. site) was the interaction of that factor by block within site (e.g. site x block within site). Each factor interaction(s) (e.g. day length x moisture) was similarly tested by the interaction of that factor interaction by block within site (e.g. day length x moisture x block within site) etc. In total, 16 error terms were created for each variable analysed.

RESULTS

Shoot length is determined by its components, NSU and SUL. Therefore, the effect of nursery pretreatment and site on these components are considered before addressing their combined effect on shoot length. Only mean pretreatment and site effects that are most representative of the data are presented in the figures.

Number of Stem Units and Lammas Growth

Planting site ($p<0.001$) and the nursery pretreatments - moisture ($p<0.01$), day length ($p<0.05$), cavity size ($p<0.05$), lift ($p<0.05$) - and the interactions of day length by lift ($p<0.01$) and site by day length by lift ($p<0.01$)

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[5] A stem unit is "an internode, together with the node and nodal appendages at its distal extremity" (Doak 1935). Needles and lammas bud scales are stem units of interest in this study; both types underwent internodal expansion.

significantly influenced final NSU. However, the results for all except site effects are confounded by differences among pretreatments in preformed NSU.

Differences among nursery pretreatments in NSU on the NW site within lift N seedlings (fig. 1A) closely paralleled final needle primordium numbers recorded in the nursery study (O'Reilly et al. 1989b). Seedlings pretreated to moisture stress and long days had the least number of needle primordia at planting, the effect of the former being greater than the latter. Seedlings from the SDW pretreatment had the greatest number of primordia at planting.

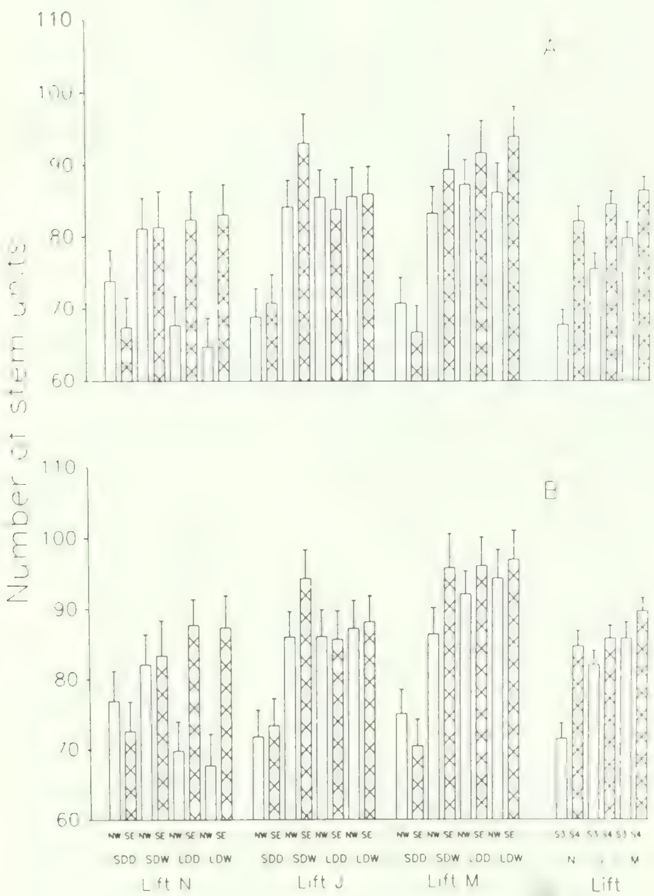

Figure 1.--Mean number of stem units before (A) and after (B) lammas growth has occurred during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively. Vertical lines indicate 1 SE.

Seedlings from the SE site usually produced the most NSU, but this varied with nursery preconditioning. Seedlings from SDD had no free growth or produced few new stem units during free growth across all lifts and on both sites. Few new stem units were produced during free growth in seedlings pretreated to SDW from any lift-storage precondition on the NW site, but those from lifts J and M produced some free growth stem units on the warmer SE site. Seedlings of both moisture levels pretreated to LD showed a similar pattern across all lifts and both sites. Within the November-lifted stock, seedlings pretreated to LD showed a much different pattern than those that received SD. Seedlings pretreated to LD within lift N produced many new stem units during free growth on the SE site, but few on the NW site. Seedlings from other lifts within this pretreatment produced many stem units during free growth.

Seedlings from S4 had greater NSU than those from S3, mainly due to differences in fixed NSU (O'Reilly et al. 1989). On average, seedlings from S4 had 10 needle primordia more at planting than those from S3. However, there were large differences in NSU between lifts for seedlings from S3 at the end of the field season, but small differences in those from S4 (fig. 1A). These differences occurred mainly due to the greater amounts of free growth stem units produced in S3 seedlings from lifts J and M and in those from S4 within lift N. Differences were relatively consistent across the pretreatments within each lift.

The frequency of lammas growth varied with site and nursery pretreatment (fig. 2). The highest frequency of lammas shoots was in seedlings from lifts N and M, especially in those from S3. Differences in lammas shoot frequencies combined with variation in lammas NSU are reflected in final NSU values (fig. 1B). Note the general increase in NSU in seedlings from lift M and in those from S3 within the J and M lifts. Seedlings from the smaller cavities produced the least NSU, especially those from lift N.

Stem Unit Length

Stem unit length varied significantly due to nursery pretreatments - lift ($p<0.001$), day length ($p<0.05$) and day length by moisture stress ($p<0.05$). Lifting date had a large and consistent effect on mean SUL, but the influence of dormancy induction pretreatment was variable (fig. 3). Plants from lift N had the shortest SUL. Seedlings pretreated to LD had larger mean SUL than those from SD. Plants of both moisture levels in the nursery within LD had similar SUL but those stressed within SD had very short SUL. Planting site by day length effects appear

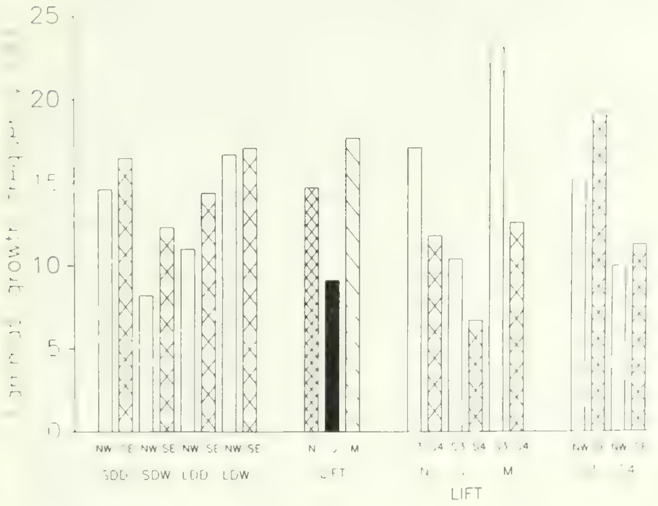

Figure 2.--Lammas growth frequencies (%) during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively.

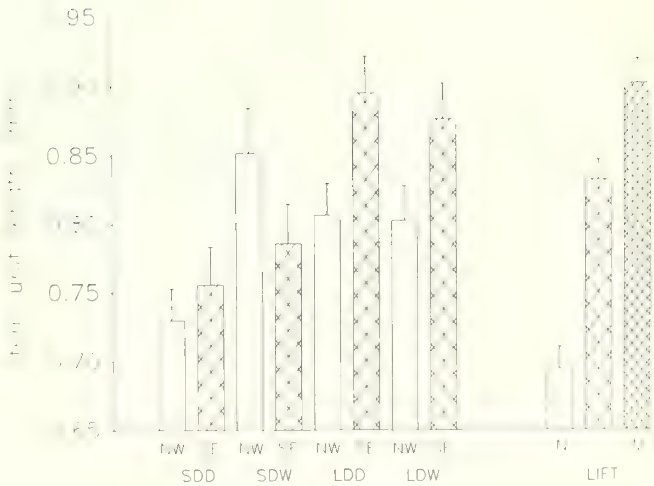

Figure 3.--Stem unit length at the end of shoot growth during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. Vertical lines indicate 1 SE.

substantial, although these were not significant ($p<0.09$). Site means are presented because they had an important effect on final shoot length when combined with the influence of NSU. Plants from the SE site had larger SUL when pretreated to LD and SDD, while those pretreated to SDW showed the reverse pattern. There were no significant differences in SUL between the lammas and fixed-free portions of the shoot.

Shoot Length

Field height growth was significantly affected by the nursery pretreatments - lifting date ($p<0.001$), day length ($p<0.01$), moisture ($p<0.05$), cavity size ($p<0.05$) and day length by site ($p<0.01$), moisture by day length ($p<0.05$).

Seedlings from SDD conditions in the nursery had the shortest shoots due to the short SUL and low NSU (fig. 4A). Shoot length in those pretreated to SDW were much greater than those pretreated to SDD because they had more stem units in their overwintering buds (O'Reilly et al. 1989b) and had greater SUL. Number of free growth stem units was not a major factor for seedlings pretreated to SD. Shoot length in SDW seedlings was similar on both sites, but this was achieved in different ways. Seedlings on the NW site had greater SUL but had fewer stem units than those on the SE site. Seedlings from both moisture levels of the LD pretreatments had similar final shoot length. Shoot length of plants from the NW site of this pretreatment was similar to those from SDW. The greater growth achieved in the LD pretreated plants on the SE site was mainly due to the greater SUL, although NSU produced during free and lammas growth also contributed.

Differences in shoot length due to cavity size resulted from differences in NSU only. Seedlings from the larger cavities had greater preformed NSU (O'Reilly et al. 1989b). However, seedlings from S3 produced more free growth and lammas growth than those from S4 (fig. 4B).

Lammas growth had the largest effect on seedlings from S3, especially in those pretreated to LD. This effect of LD was not apparent in the NSU (fig. 1) and lammas frequency data (fig. 2); the much greater SUL combined with greater NSU resulted in substantial shoot length differences in these seedlings. Changes in final shoot length due to lammas growth were generally greatest in seedlings from lifts N and M and on the SE site, especially in those from SDD on that site.

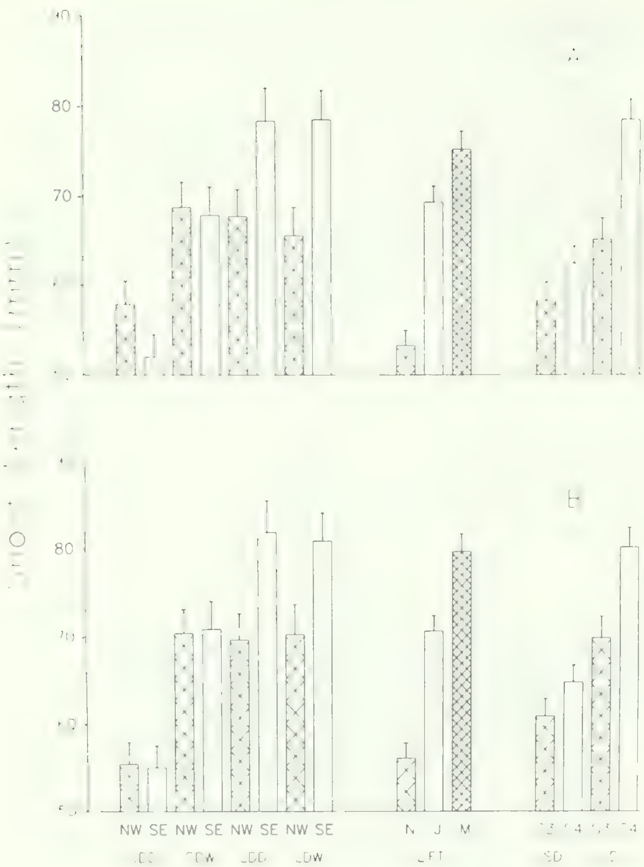

Figure 4.--Shoot length before (A) and after (B) lammas growth has occurred during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. SD and LD refer to short- and long-day pretreatments, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively. Vertical lines indicate 1 SE.

DISCUSSION

Shoot length is determined by the number of stem units and stem unit length; the former is considered far more important than the latter in this regard (Cannell et al. 1976). These components of shoot length are thought to vary independently (Cannell 1979), although this may not always be the case (Kremer and Larson 1983; Bongarten 1986; Hallgren and Helms 1988). Most NSU in seedlings of western hemlock were preformed, i.e. they were initiated by activity of the apical meristem during nursery growth (O'Reilly et al. 1989b). In contrast, SUL is determined by activity of the intercalary meristems located between the needle primordia and subsequent cell elongation. Therefore, final SUL is determined by processes that become activated mostly during field growth.

Variation in NSU due to nursery pretreatment in the portion of the shoot that elongated before lammas growth took place (fig. 1A) largely agreed with that measured in the nursery study (O'Reilly et al. 1989b). The influence of lifting date mostly reflected differences in NSU produced during free growth because date of lifting had little effect on final primordium numbers in the nursery study (O'Reilly et al. 1989b). In addition, planting site had a significant influence on NSU across all lifts, site effects being largest within the LD November-lifted stock.

Seedlings from the short days and moisture stress pretreatment had short SUL, with little difference due to planting site. These seedlings produced few additional stem units during free growth, and combined with their very short SUL, produced very short shoots. Seedlings with a large number of needles are most susceptible to moisture stress during elongation (Hallgren and Helms 1988), perhaps accounting for the shorter SUL in seedlings from SDW growing on the warmer SE site (fig. 3). Furthermore, seedlings from the SD pretreatment, especially those from SDW of lift M, flushed their buds more rapidly than other seedlings (O'Reilly et al, unpubl.). Flushing rates were most rapid on the SE site, perhaps making them susceptible to moisture stress during early shoot elongation. The 1987 growing season was warm and dry at the study sites[6]. Also, competition for metabolites among elongating stem units may have resulted in the shorter SUL on the SE site where some free growth took place, a hypothesis first proposed by Kremer and Larson (1983) to explain the negative correlation found between NSU and SUL in seedlings of Pinus banksiana Lamb. The large number of preformed needles in seedlings from SDW (O'Reilly et al. 1989) combined with adequate SUL allowed good shoot growth in the field. Seedlings pretreated to LD in this study were of higher physiological quality (Arnott et al. 1989), thus explaining their superior shoot growth achieved through increased SUL as well as through the production of additional NSU during free and lammas growth, especially on the SE site.

Differences in final shoot length due to cavity size were attributable to differences in NSU only. The larger NSU that were predetermined in seedlings from S4 than in those from S3 (O'Reilly et al. 1989b) explained most of these differences. Similarly, plant spacing in the

[6]Data on file, Canadian Forestry Service, Victoria, B.C.

nursery had a large effect on height growth up to 3 years after field planting in seedlings of Douglas fir (van den Driessche 1984).

Interestingly, lammas growth was most frequent in seedlings from S3 and in those from lifts N and M. Because of the superior physiological quality and greater vigour of lift M stock (Arnott et al. 1989), it is not surprising that they had a high frequency of lammas shoots. The relatively high frequency of lammas growth in the November-lifted stock probably was related to the physiological and developmental characteristics of these seedlings. Seedlings from this lift flushed much later in the field than those from other lifts (O'Reilly et al, unpubl.), probably because its dormancy intensity was very high at time of planting (Arnott et al. 1989). In addition, these plants began bud development at an earlier date than those from other lifts, and they often resumed growth after producing a few bud scales only (O'Reilly et al., unpubl.). The late release from dormancy combined with earlier date of bud formation perhaps made these plants prone to lammas growth. Lammas shoot length was very short in these seedlings because they produced few lammas stem units and had short SUL. The high frequency of lammas growth on seedlings from S3 is more difficult to explain. Seedlings from S3 were smaller but had greater apical dominance than those from S4 (O'Reilly et al. 1989a); such plants may have been more responsive to environmental changes that induce lammas growth.

The confounding effect of seedling size at planting on shoot growth except for that of cavity size has not been addressed in this paper. Seedlings treated to LD were about 25% taller and were much more heavily branched (O'Reilly et al. 1989a). Moisture stress had a smaller effect on seedling size while lifting date had a negligible effect on these characteristics. Seedlings treated to SDW grew adequately in the field relative to planting height, but these plants had the advantage of having many preformed stem units. Seedling size at planting was not considered because it would complicate data analysis and interpretation further.

CONCLUSIONS

Spring lifting followed by immediate field planting provide the best shoot growth during the first year of field establishment in western hemlock seedlings. Seedlings subjected to long days during dormancy induction in the nursery achieved better shoot growth after outplanting than those treated to short days. Moisture stress in the nursery had little effect on shoot growth in the field of seedlings from the LD pretreatment but greatly reduced shoot growth of those from the SD pretreatment. Because most stem units were preformed during bud development in the nursery, differences in SUL had a larger impact on shoot length than differences in NSU. Lammas growth was most frequent in seedlings from the smaller cavities and in those from the November and March lifts.

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Field Performance of Five Interior Spruce Stock Types with and without Fertilization at Time of Planting[1]

Craig Sutherland[2] and Teresa Newsome[3]

Abstract.--The purpose of this experiment was to compare the initial field performance of interior spruce seedlings by container size, root pruning, and fertilization at time of planting. Increasing the container size significantly improved seedling performance after five growing seasons. Mechanical or chemical root pruning and fertilization at time of planting made no significant improvements to seedling performance.

INTRODUCTION

Field performance of spruce seedlings is a concern to both nurserymen and foresters because of the inherent slow initial growth of spruce and the fact that most spruce sites are prone to invasion of non-crop vegetation. The Cariboo Forest Region is no exception. A study concerning plantation performance in the Cariboo found that both bareroot and small container (PSB 211) spruce obtained an average height of only 50 cm after five growing seasons (Vyse, 1981). Many spruce plantations quickly get chocked out by such species as fireweed (Epilobium angustifolium) which restrict light availability, nutrient and water uptake and cause mechanical damage to seedlings through vegetation press. If spruce could compete more effectively with non-crop vegetation by initially being larger in height and caliper and by exhibiting faster growth responses one would expect the seedlings would be at a competitive advantage to the brush.

The objectives of this experiment were to 1) compare the early field performance of five experimentally produced containerized stock types; 2) assess the effects of root pruning; and 3) assess the effects of slow-release fertilizer applied at the time of planting.

This trial was established in four Forest Regions of British Columbia. The results presented in this paper are from the trial estabished in the Cariboo Forest Region.

METHODS

The trial was established on a recently burned clear cut in the Cariboo Forest Region, situated in the interior of British Columbia. The site was classified according to the Biogeoclimatic Classification System (Coupe' and Yee, 1982) as the Interior Cedar Hemlock (h) Subzone with an elevation of approximately 950 m.

The trial was established as a split-plot design with fertilizer as the main plot factor and stock type as the split-plot factor. Four blocks were established on the site.

Five different stock types of British Columbia interior spruce (Picea glauca x engelmannii) were grown at the Ministry of Forests' North road Lab in 1980, in Victoria, B.C. by A.N. Burdett in 1980 (table 1).

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[1]Paper presented at the 1988 Conference of the Western Forest Nursery Council and Forest Nursery Association of British Columbia, Vernon, British Columbia, August 8-11, 1988.

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Table 1.--Five stock types of British Columbia interior spruce

Stock Type	Root Pruning
CBR 1010 1+0 [1]	Boxed (Mechanical)
PSB 615 1+0 [2]	None
PSB 415 1+0	Copper (chemical)
PSB 415 1+0	None
PSB 313 1+0	None

1 Container grown bareroot from a (10 x 10 x 10 cm boxed container)

2 Plug Stryro Block container

Forty grams of Osmocote fertilizer (18-6-12) was placed in a 15 cm radius around the base of each seedling at the time of planting. One half of each stock type was fertilized and the other half left as a control.

All seedlings in the five stock types by two fertilization treatments were monitored at the end of each growing season for seedling survival, total height (cm), leader growth (cm), stem diameter (mm), condition and for vegetation cover. An ANOVA was used to analyse the data.

RESULTS AND DISCUSSION

Stock Type

Seedling Survival

Seedling survival was excellent across all treatments after five growing seasons. There were no significant differences between average treatment survivals which ranged from 94 to 96%.

Seedling Height Growth

The PSB 615 and CBR 1010 stock types were significantly taller than the other stock types when planted and they have been able to maintain this height superiority for five growing seasons (fig. 1). The total heights of the PSB 615 and CBR 1010 container seedlings after five years were close to one meter in height which was higher than the competing non-crop vegetation. These averages are significantly taller than the 70 to 80 cm heights obtained by the other three stock types which were still competing strongly for light with the non-crop vegetation.

This height superiority can be further illustrated by looking at relative growth rates (fig. 2). Relative growth rate (R.G.R.) is a comparison of a stock types total seedling height and its previous year's height. Relative growth rate is expressed by the slope of each line. Since each stock types R.G.R.'s have parallel slopes, this would indicate that the larger stock types (PSB 615, CBR 1010) are maintaining height superiority. The taller stock types are producing taller terminal leaders and are reaching a free growing state sooner than the shorter stock types.

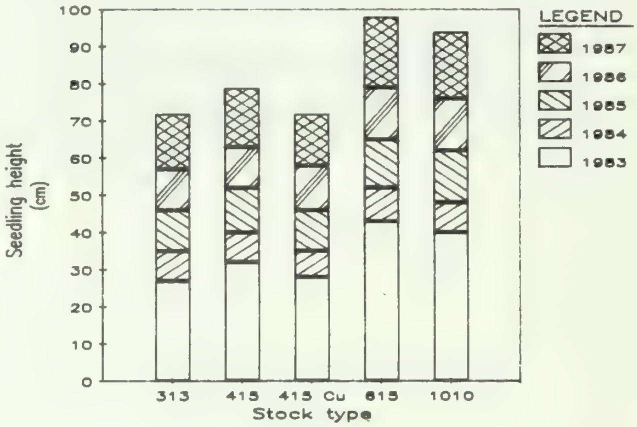

Figure 1.--Total seedling height of five interior spruce stock types by growing season.

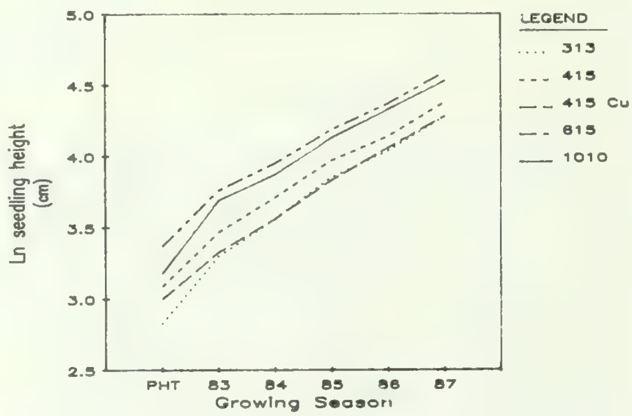

Figure 2.--Relative height growth rate of five interior spruce stock types.

Seedling Diameter Growth

The PSB 615 and CBR 1010 stock types were significantly larger in diameter than the other stock types when planted and they have also been able to maintain a diameter superiority for five growing seasons (fig. 3). The total diameters of the PSB 615 (28 mm) and CBR 1010 (25 mm) seedlings are significantly larger than the 19 to 22 mm diameters produced by the other three stock types. The taller stock types are now receiving increasing amounts of light and so are able to allocate more carbohydrates to the root systems which directly increases diameter growth.

Again this diameter superiority can be further illustrated by looking at relative growth rates (fig. 4). Since the slopes of the lines are parallel the R.G.R.'s are comparable. The larger stock types which have larger root collar diameters are becoming more resistant to vegetation press than the smaller stock types.

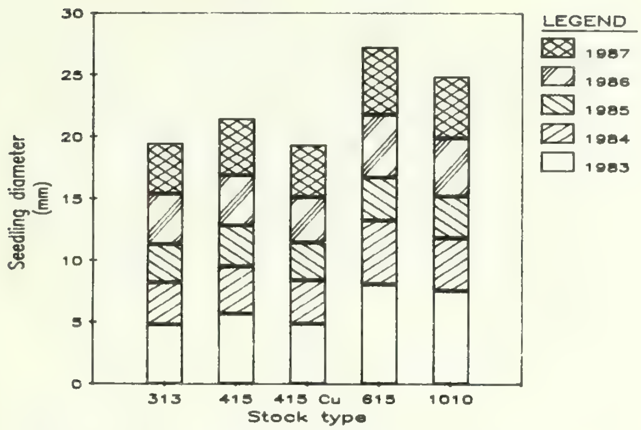

Figure 3.--Total seedling diameter of five interior spruce stock types by growing season.

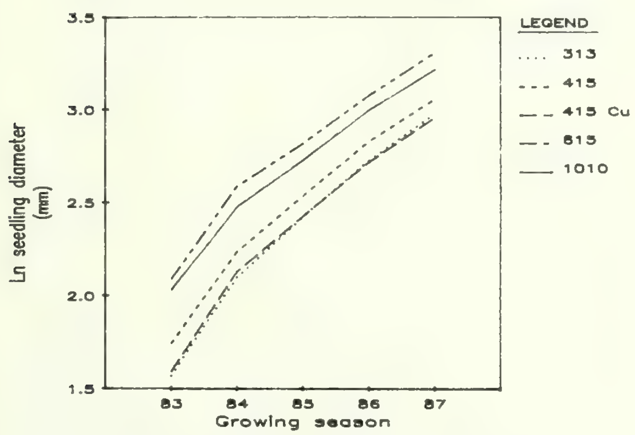

Figure 4.--Relative diameter growth rate of five interior spruce stock types.

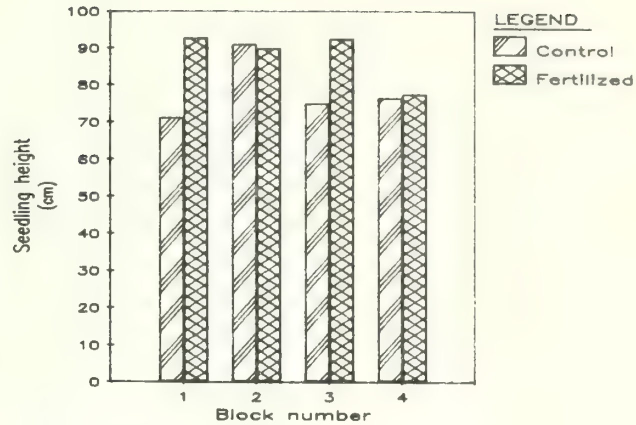

Figure 5.--Total seedling height of the fertilized and control treatments for all stock types within each block.

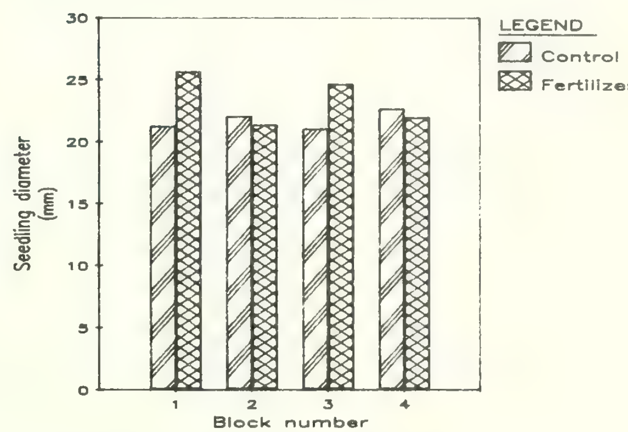

Figure 6.--Total seedling diameter of the fertilized and control treatments for all stock types within each block.

Fertilization

Osmocate fertilization produced an irregular response but overall it did not significantly improve seedling height or diameter growth. Brockely (1988) stated that response to fertilization has not been consistent in the past. This study confirms his statement by identifying treatment response irregularities between the four blocks (fig. 5 and 6). Although this study was not designed to test site differences, the data suggests that the better growth responses to the fertilizer treatment (Block 1 & 3) occurred on mesic sites and the poor growth responses (Block 2 & 4) occurred on submesic and subhygric sites respectively.

Root Pruning

The purpose of mechanical or chemical root pruning was to stimulate lateral root development in container plugs. The height and more importantly diameter growth responses indicate that the mechanical root pruning of the CBR 1010 stock and the chemical root pruning of the PSB 415 copper treated stock had little or no effect on seedling growth.

Insect Damage

Pissodes strobi (terminal spruce weevil) attacked approximately 10 percent of the PSB 415 and 615 and CBR 1010 seedlings and 5 percent of the PSB 313 and 415 CU seedlings. The attack has concentrated on the taller stock types and where the frequency of tall seedlings was high. This insect attack once again points out that seedlings reaching a height defined, free growing state may not necessarily be free to grow.

CONCLUSIONS

1. Seedling survival ranged from 94 to 96 percent across all treatments after five growing seasons.

2. The PSB 615 and CBR 1010 stock treatments produced significantly larger height and diameter growth responses than the PSB 415, 415 CU and 313 stock treatments.

3. Fertilization produced irregular results but generally did not improve growth response.

4. Mechanical or chemical root pruning had little or no effect on seedling growth response.

5. Pissodes strobi are attacking young seedlings and protection measures must be taken once seedlings have reached a free growing status.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. A.N. Burdett for initiating and coordinating the trial and Mr. A. Vyse for establishing the trial in the Cariboo.

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Impact of Lift Date and Storage on Field Performance for Douglas-fir and Western Hemlock[1]

B.G. Dunsworth[2]

Abstract.--This study was established to assess the impact of changes in seedling morphology and physiology on outplant performance of western hemlock and Douglas-fir.

The six lift/store regimes in this experiment led to greater changes in seedling physiology than seedling morphology. The regimes created a wide range of dormancy intensities and frost hardiness for both species. Frost hardiness, as assessed by electrolyte leakage, was more closely related to dormancy intensity than was foliage browning. Storage regimes reduced the rate of dormancy release and maintained frost hardiness relative to no storage.

Field performance results from unwatered, raised beds indicate that early planting dates (Jan. 15) had the best relative volume growth. Storage maximized relative volume growth for both species for the March 15 and May 15 planting dates. Electrolyte leakage and dormancy intensity were the best predictors of volume growth.

ACKNOWLEDGEMENT

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INTRODUCTION

For a number of years there has been a contentious debate among coastal nursery growers and field users about the appropriateness of winter lifting and storage of planting stock (Stone and Schubert 1959a, Hermann et al. 1972, Jenkinson and Nelson 1978, Krueger 1966, Nelson and Lavender 1979). Today, many foresters feel that cold storage is detrimental. They subsequently demand hot planting stock when they can, particularily for late spring planting.

This sentiment has been reinforced by erratic survival and poor growth in Douglas-fir, western red cedar, and ponderosa pine bareroot stock cold-stored for several months prior to planting (Stone and Schubert 1959b, Stone et al. 1961, Hocking and Nyland 1971, Curran and Dunsworth 1987, Van Den Driessche 1977).

Cold storage has been associated with the following problems:

- molds,
- loss of carbohydrate reserves,
- reduction in root growth capacity,
- loss of dormancy intensity, and
- reduced frost hardiness and stress resistance.

Although the potential for physiological deterioration exists, the literature indicates that the rate of deterioration is accelerated without cold storage (Ritchie and Dunlap 1980, Burdett and Simpson 1984, Garber and Mexal 1980, MacDonald et al. 1983).

However, cold storage may create an acclimation problem, particularily with late spring planting. Investigations with boreal species in eastern Canada suggest that the stresses of acclimation may be greatest for cold-stored stock (Grossnickle and Blake 1987). Whether this is true in coastal species and whether the maintenance of a higher level of stress resistance is a compensating factor has yet to be determined.

Eliminating cold storage reduces nursery operating costs but creates a logistical problem. Persistent delays in handling the last season's crop leads to delays in starting the next season's crop. Coastal, container nursery growers need to determine if there is good biological foundation to the belief that cold storage is a detrimental practice. They also

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1 Paper presented at the 1988 Western Forest Nursery Association Meeting, August 8-11 (Vernon, B.C., Canada)

2 MacMillan Bloedel Limited, Woodlands Services Division, 65 Front Street, Nanaimo, B.C. Canada V9R 5H9

need to know if there is sufficient variation among seedlots to justify a range of winter lift regimes.

Our initial look at the problem focused on:

1. The predictive relationships among morphological and physiological characterizations at lift with subsequent field performance.
2. The progression and interrelationships among physiological characterizations from January to May under stored and non-stored conditions.
3. Potential optimum lift/store regimes.

METHODOLOGY

This experiment consists of two parts:

1. Seedling characterization.
2. Seedling performance.

The experimental approach is to create as wide a range of morphological and physiological kinds of seedlings using species, cavity size and lift/store regime as is practicable. These are then exposed to a simulated outplanting, under conditions where soil moisture and temperature can be measured and controlled. Seedlings able to maximize survival and growth under these conditions can then be associated with a specific cultural regime.

Seed Source and Lift/Store Treatments

The following species and stocktypes were grown at the Angus P. MacBean Nursery during 1985:

Table 1.--Seedlots and stocktypes used for Douglas-fir and western hemlock.

Douglas Fir			Western Hemlock	
Seedlot/ Elevation	Stock Type		Seedlot/ Elevation	Stock Type
	PSB 313	PSB 415		PSB 313
4504/579	X		7311/150	X
7320/915	X		18752/416	X
4505/610	X	X		

The lift/store regimes shown in Table 2 were applied to each of the species and stocktypes shown in Table 1.

Seedling Characterization

Seedlings were characterized for morphology and physiology at lift and at the end of storage.

Morphology

Twenty-five trees per treatment (five trees for five replicates) were assessed for height, caliper, shoot and root dry weight.

Physiology

Seedlings from each treatment were assessed for Root Growth Capacity (in two environments),

Table 2.--Lift dates and storage duration treatments for Douglas-fir and western hemlock.

Lift Date	Storage Duration (months) at +2 C		
	0	2	4
01/15/86	T1	T2	T3
03/15/86	T4	T5	
05/15/86	T6		

Dormancy Release Intensity, and Frost Hardiness (foliage browning and electrolyte leakage).

Root Growth Capacity.--Twenty-five seedlings (five trees from five replicates) per treatment were grown for one week in a peat/vermiculite/sand medium (2:1:1) in each of two environments (75% RH, 16 hr photoperiod, and 400 $\mu mol/s/m^2$ common to both):

1. 22 C/18 C (day/night) (D/N)
2. 30 C/25 C (D/N)

Seedlings were kept at field capacity for one week and assessed for root elongation using the index of root growth (IRG) (Burdett 1979).

Dormancy Release Index.--Twenty-five trees (five trees from five replicates) per treatment were assessed for number of days to budburst. The test environment was a 20 C D/N greenhouse with 16 hour photoperiod. Seedlings were kept at field capacity for the duration of the test. The index was calculated as:

DRI= 10/# days to budburst (Ritchie 1984)

Frost Hardiness.--The risk of frost damage was assessed using foliage tissue in two ways:

1. Foliage Browning--qualitative (visual) assessment of the percent of foliage browned after exposure (-18 C) and one week of growth at room temperature and field capacity.
2. Electrolyte Leakage--quantitative assessment of cell membrane leakage of electrolytes due to stress or damage by frost (-18 C). Assessment consists of a comparison of conductivity measures for diffusate from frost damaged, undamaged, and heat killed foliage (Colombo and Cameron 1986).

Seedling Performance Study

The field study was designed as a completely randomized experiment consisting of six lift and store regimes and six species/stocktype treatments each replicated three times. Replicate plots consisted of twenty tree-row plots at 15 x 15 cm spacing. This test was planted into a 4 m x 8 m x 70 cm wooden soil box consisting of an alluvial,

silty sand soil. The box was covered with a 6 mm, polyethylene sheet roof. This allowed rain to be excluded and still achieve approximately 75% full sunlight.

All seedlings were grown in the raised beds for one growing season. In December, all surviving seedlings were measured for height and caliper and carefully excavated. Shoot and root dry weights were determined for treatments; replicates were pooled.

The field performance results described here pertain to the dry moisture regime. This regime received no watering during the growing season. Soil tension at 20 cm exceeded -5 bars for greater than 100 days; soil temperature at 10 and 20 cm exceeded 20 C for up to 60 days.

RESULTS AND DISCUSSION

Seedling Characterization

Morphology At Lift

Height over all lift dates ranged from 16 to 23 cm. Western hemlock seedlings tended to be taller than Douglas-fir. Caliper ranged from 2.2 to 3.7 mm, with the latest lift having the largest calipers for all seedlots.

Shoot dry weight extended from 0.8 to 3.0 g, with a consistent trend of increasing weight from later lift dates. Western hemlock had consistently higher shoot weight than Douglas-fir for all lifts. Root dry weight varied from 0.6 to 1.6 g and exhibited a consistent increase with later lifts. This was less dramatic than increases in shoot dry weight.

Shoot to root ratios tended to increase with later lift dates. Western hemlock had larger ratios than Douglas-fir for the first two lifts, but by May 15 both species were comparable (Figure 1).

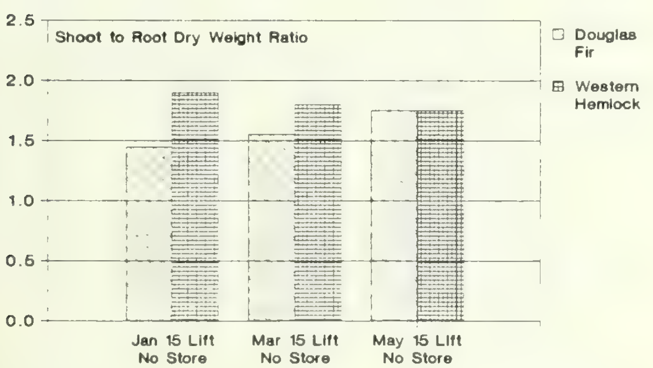

Figure 1.--Shoot to root ratio for three lift dates averaged by species.

The other measures of seedling balance (height:caliper and caliper:mass) tended to decrease with later lifts (Figure 2).

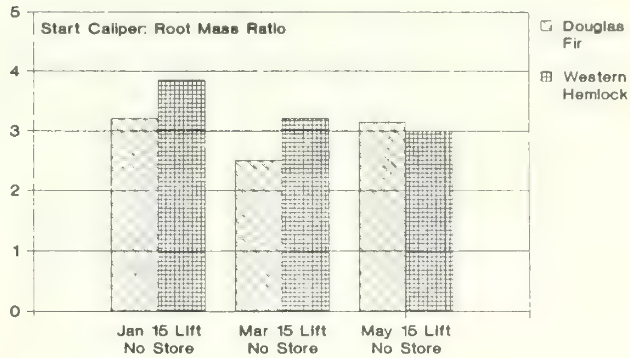

Figure 2.--Caliper to root mass ratios for three lift dates averaged by species.

Species differences in morphology were most pronounced for the earliest lift. Western hemlock was taller, thinner, and less balanced than Douglas-fir. These differences were negligible by the last lift.

Physiology At Lift and During Storage

Root growth capacity (index of root growth) was high for both hot (30/25 C, D/N) and cool (22/18 C, D/N) tests over all species and lift/store regimes. The cool test tended to have higher values and a slightly narrower range than the hot test (Figure 3). In both tests, western hemlock had higher RGCs than Douglas-fir for most lift/store regimes.

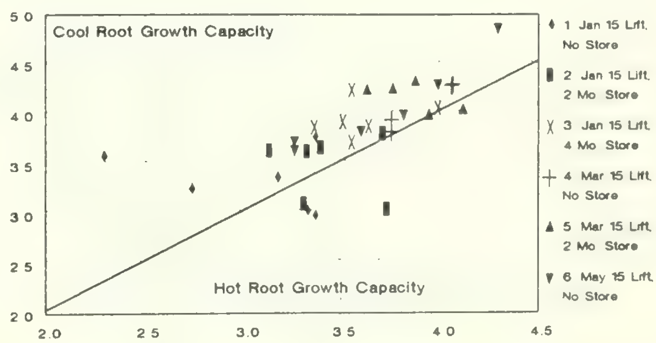

Figure 3.--Comparison of hot and cool root growth capacity test results (points are species/stocktype averages).

In assessing the progression of RGC over lift dates, Douglas-fir tended to increase RGC to March 15 and then decrease slightly to May 15. This was most pronounced in the hot test. Western hemlock, on the other hand, increased RGC consistently with later lift dates. Storage duration did not have a

significant negative effect on RGC in either species.

Dormancy intensity consistently weakened (index values increased) with increasing lift date (Figure 4). The impact of storage at both January 15 and March 15 was to reduce the rate of dormancy release relative to unstored stock for the same planting date. Douglas-fir had slightly more rapid dormancy release than western hemlock for both stored and unstored comparisons.

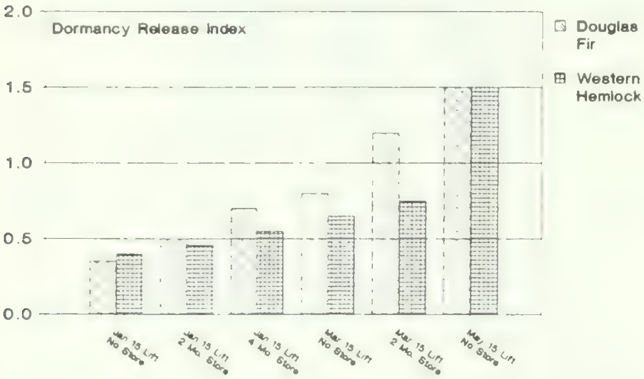

Figure 4.--Dormancy intensity averages for Douglas-fir and western hemlock over the six lift/store treatments.

Frost hardiness (-18 C) weakened with later lifts. The largest difference occurred between January 15 and March 15 lifts (Figure 5). Differences between species were not pronounced or consistent. Cold storage sustained good frost hardiness. In several seedlots, the stored versus non-stored differences in foliage browning were as high as 70 to 80 percent.

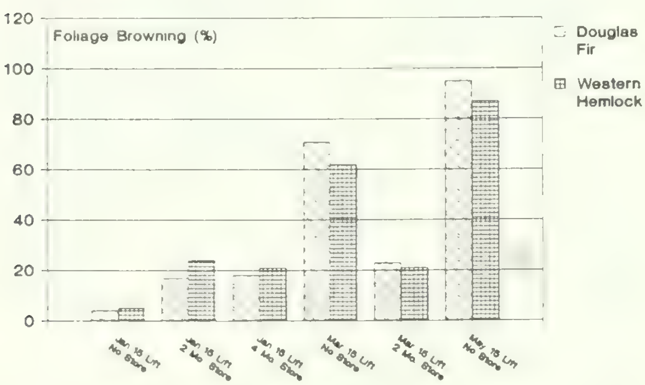

Figure 5.--Frost hardiness (foliage browning at -18 C) averages for Douglas-fir and western hemlock over the six lift/store treatments.

The conductivity test showed a more continuous pattern of change over the lift/store treatments and more consistent trends between species (Figure 6). Western hemlock was more frost tolerant than Douglas-fir with the odd exception of the last lift. From the March 15 lift to the May 15 lift, Douglas-fir showed a marked reduction and western hemlock an increase in index of injury.

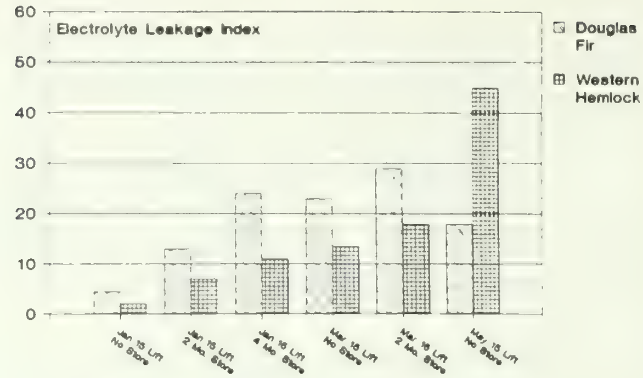

Figure 6.--Electrolyte leakage (Index of Injury) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Comparisons Among Physiological Tests

The physiological tests in this study each provide slightly different information about seedling function. RGC indicates the ability to initiate and elongate roots. Electrolyte leakage indicates the degree to which the foliage has been stressed or damaged from frost exposure. The foliage browning test is a qualitative measure of cellular damage resulting from exposure to frost.

The comparison of "hot" versus "cool" RGC test environments has been discussed previously. In general, the cool test raised the RGC relative to the hot test (Figure 3) suggesting that the hot environment is beyond the photosynthetic optimum (W. Binder, pers. comm.). Also, rankings changed within and among lift/store treatments, with the most pronounced changes within treatments. For the remaining discussion, the comparisons to RGC will refer to the cool test which is now the B.C. Ministry of Forests' standard.

RGC and electrolyte leakage (index of injury) exhibited a positive linear relationship with dormancy intensity (dormancy release index) over all treatments. This appears to be at odds with the hypothesis put forward by Ritchie (1985) which suggested a strong, alternate cyclic pattern in RGC and frost hardiness as dormancy intensity weakens.

In the foliage browning frost hardiness test, the relationship with dormancy intensity partitions into two distinct groups: cold-stored and non-stored (Figure 7). The cold-stored stock from either the January 15 lift or the March 15 lift all had less than 40 percent frost damage. The non-stored stock ranged up to 95 percent damage by May 15. As Ritchie (1984, 1985) has shown for bareroot Douglas-fir, the effect of cold storage in this study was to reduce the rate of dormancy release and markedly reduce the rate of loss of cold hardiness.

Electrolyte leakage does not exhibit the same tight, treatment clusters as foliage browning (Figure 8). This may be because the test integrates stress and damage as they effect cell membrane permeability and function. Subsequently, for

the same level of foliage damage, we can have very different levels of electrolyte leakage within a given lift/store treatment.

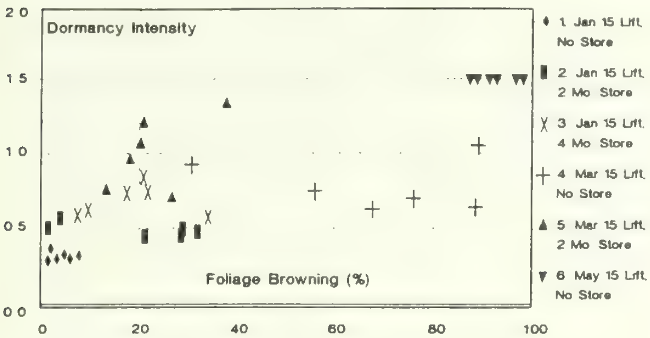

Figure 7.--Comparison of dormancy intensity and frost hardiness (foliage browning at 18 C) for Douglas-fir and western hemlock over the six lift/store treatments.

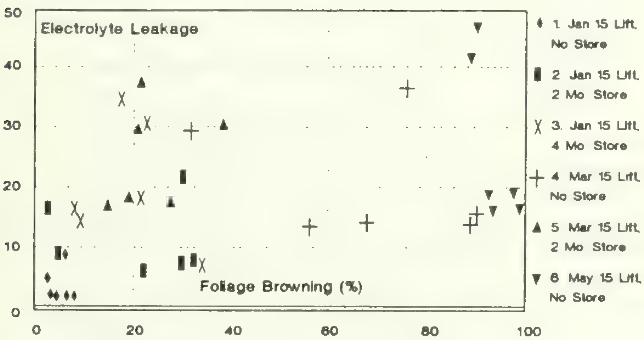

Figure 8.--Comparison of frost hardiness (foliage browning at -18 C) and electrolyte leakage (Index of Injury for Douglas-fir and western hemlock over the six lift/store treatments.

Field Performance

Survival

Survival ranged from 88 to 100 percent, indicating that all lift/store regimes resulted in stock with sufficient stress resistance to survive high seasonal root zone temperatures and persistent drought.

Growth

It should be realized that the nature of the lift/store and plant regimes is such that growing seasons may differ by as much as 120 days.

Height growth.--Relative height growth (growth/initial height) ranged from 0.35 to 0.80 (Figure 9). The trend was for later lifts to have greater height growth. Douglas-fir tended to have a narrower range than western hemlock and a much weaker tendency for later lifts to exhibit more growth. Storage appeared to have an indeterminate effect on Douglas-fir, but a marked negative effect on western hemlock.

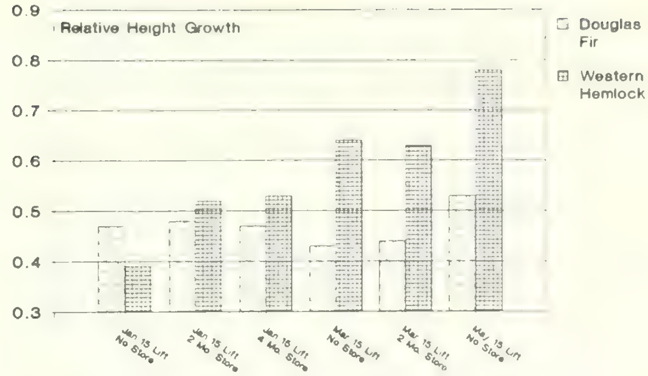

Figure 9.--Relative height growth (growth/initial height) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Caliper growth--Caliper growth tended to show the reverse relationship to lift/store regimes that was evident with height growth. Early lifts had the best relative caliper growth. Stored stock had comparable or better caliper growth for March 15 or May 15 planting dates. The pattern of caliper growth over lift/store regimes tended to be more consistent between species than with height growth.

Volume growth--Relative volume growth (volume growth/initial volume) integrates height and caliper growth but with more emphasis on caliper than height. Subsequently, the pattern of volume growth over lift/store regimes mimics that of caliper growth.

Early lifts have the highest relative volume growth (Figure 10). Western hemlock and Douglas-fir tended to respond similarly to storage. Stored stock had comparable or better volume growth than non-stored stock for the same planting date. This was particularly evident for the May 15 planting date for both species where the January 15 lift with four months storage had 20 to 25 percent better relative volume growth than the March 15 lift with two months storage, and 50 to 75 percent better relative volume growth than non-stored stock.

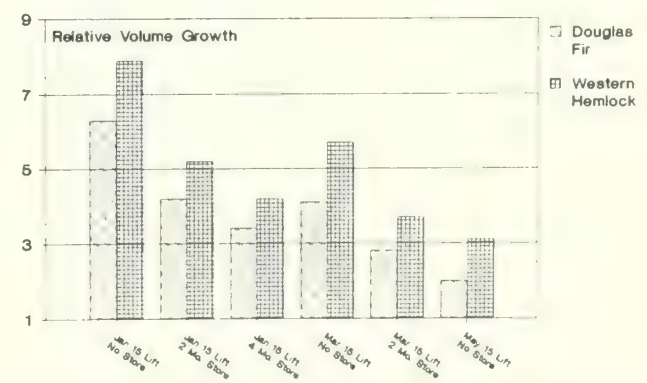

Figure 10.--Relative volume growth (growth/initial volume) averages for Douglas-fir and western hemlock over the six lift/store treatments.

These differences in height, caliper and volume growth are a function of length of growing season and of differing physiological responses to the outplanting environment. They result from changes in water relations and gas exchange which ulti-

mately impact on photosynthesis, total biomass production, and the partitioning of biomass above and below ground.

Biomass Production and Partitioning

Total biomass growth for both species ranged from 3.5 to 5.5 g dry weight. Western hemlock tended to produce more biomass than Douglas-fir for any given lift/store combination. Storage resulted in comparable or greater biomass production for both species for either the March 15 or May 15 planting dates. Storage differences were more pronounced for Douglas-fir.

The more marked difference in biomass production came from the way in which seedlots and species partitioned their seasonal biomass above and below ground (Figure 11). The general tendency over all lift/store regimes was for biomass to be allocated more below ground with later lifts.

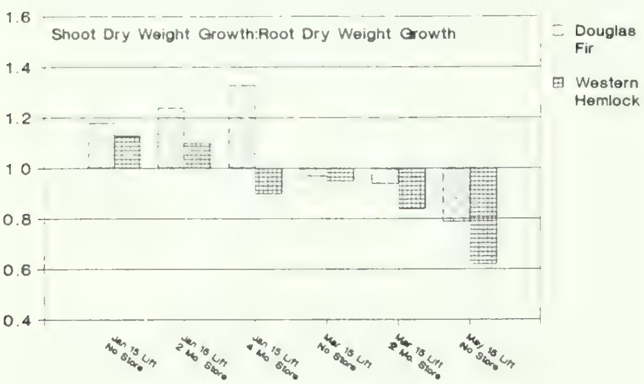

Figure 11.--Above and below ground biomass growth averages for Douglas-fir and western hemlock over the six lift/store treatments.

Storage tended to stimulate relatively more allocation to the shoot for both species in either the March 15 or May 15 planting dates. Species responded differently in the sense that western hemlock tended to be relatively more root-oriented in its partitioning than Douglas-fir for any lift/store combination. This may be a reflection of western hemlock's tendency to be a moisture stress avoider and Douglas-fir's tendency to be a moisture stress tolerator.

Western hemlock also favored the root over the shoot for the March 15, no storage and for the May 15 stored and non-stored regimes. Douglas-fir had root dominant partitioning for the March and May 15 lifts, no storage, and the March 15 lift with two months storage. The strongest shoot partitioning for Douglas-fir was for the January 15 lift, four months storage; for western hemlock, it was for the January 15 lift, no storage.

The most marked example of the differences in biomass partitioning between species was the latest planting date where, with stock stored for four months, Douglas-fir allocated about 58 percent and western hemlock about 48 percent of their total biomass growth above ground. Non-stored Douglas-fir and western hemlock, for the same planting date, allocated approximately 45 and 38 percent respectively of their biomass growth above ground.

The combination of total biomass production and allocation strategies for species and lift/store regimes correspond well with both relative volume growth and changes evident in dormancy intensity, and frost hardiness with lift/store combinations. It appears that maintenance of a relatively high level of dormancy and frost hardiness may lead to less need for damage repair following outplanting, and more in-phase development of root and shoot over the growing season.

Seedlings able to put out roots during the first part of the growing season likely experience reduced seasonal moisture stress. Higher stress resistance, less stressful post-plant conditions, and a longer growing season, led to greater total biomass growth and a larger proportion of that biomass allocated to the shoot. This resulted in shorter, fatter seedlings than those which began the season with a heavier stress load, lower stress resistance, rapid budburst, and relatively little root production.

PREDICTION OF VOLUME GROWTH

Relative volume growth was significantly correlated with dormancy intensity (r^2=0.628) (Figure 12). RGC, electrolyte leakage, and foliage browning were less well correlated (r^2= 0.375, 0.358 and 0.269 respectively). Relative volume growth tended to decrease as dormancy intensity decreased, as electrolyte leakage and foliage browning increased, and as RGC increased.

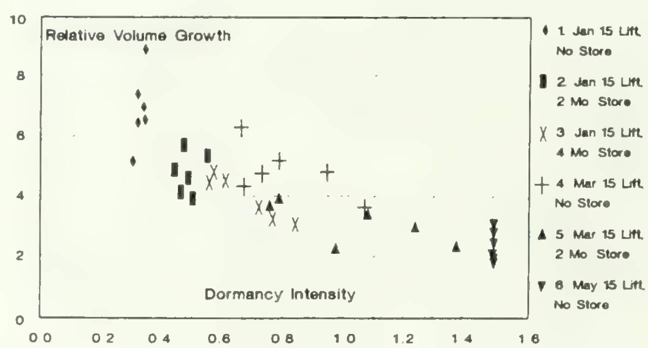

Figure 12.--Relationship between relative volume growth and dormancy intensity for Douglas-fir and western hemlock over the six lift/store treatments (points are species/stocktype averages).

It is evident that maintaining dormancy intensity in the 0.3 to 0.5 range will tend to maximize relative volume growth. This type of target would infer an electrolyte leakage (-18 C) target of less than 10, a foliage browning (-18 C) target of less than 30 percent, and an RGC target of 3.0 to 3.5.

In general, for any planting dates beyond January 15, early lifts and long storage periods maximize volume growth. The optimum lift/store regimes for both species were the January 15 lift and plant, and the January 15 lift with two months storage.

Earlier planting dates optimize stress resistance with the least stressful environmental conditions following planting. Root and shoot phenology are sufficiently "in-phase" to allow the greatest degree of drought avoidance during the first growing season. Volume growth increases as more photosynthate is produced and as less of that photosynthate is allocated to the roots or to repairing cellular damage.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation of the impact of lift and store regimes on the field performance of containerized Douglas-fir and western hemlock has indicated the following:

1. Lift date and storage duration can significantly effect seedling growth and the pattern of biomass allocation.
2. Early planting dates have the highest volume growth.
3. Cold storage maximized volume growth for both the March 15 and May 15 planting dates for both species.
4. Cold storage delayed the release from dormancy and the loss of frost hardiness relative to non-stored seedlings.
5. The best predictors of volume growth were dormancy intensity and the frost hardiness index (electrolyte leakage).

These results suggest that the following would be reasonable practices for nursery growers and seedling consumers to follow:

1. Douglas-fir and western hemlock should be lifted prior to January 15.
2. Cold storage should be used to minimize the rate of loss of dormancy and cold hardiness.
3. Planting should be done as soon as possible after lifting.
4. Targets for defining high quality stock would be:

   - dormancy release index of 0.3-0.5
   - frost hardiness (-18 C); index of injury <10 and foliage browning <30%
   - RGC >3.0.

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Auger Hole Shape, Size, and Tree Placement Affect Survival and Root Form of Planted Ponderosa Pine in South Central Idaho[1]

John Sloan[2]

Abstract.-- Ponderosa pine seedlings (2-0) were planted in 4- and 6-inch cylindrical auger holes and in 8-inch holes tapering to 4 inches at the bottom. Fifth-year mean survival of trees planted in the tapered holes was higher than three of four other treatments. The size of the planting hole as well as tree placement in the center or on the side of the hole did not affect survival. Mean seedling height after five growing seasons was unaffected by planting hole size, shape, or tree placement. Planting hole shape and tree placement impacted root system form while planting hole size did not.

INTRODUCTION

A tree depends on an adequate root system for acquisition of moisture and nutrients as well as for physical support. After establishment, planted ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings often have root morphologies drastically different from those grown from seed in place. Soil characteristics, nursery cultural practices, and planting methods of bareroot stock can all have a great influence on the form a root system may take. Root system parameters -- affected by various cultural and planting practices -- include symmetry, balance, constriction, coiling, and taproot development. Trees seeded in place tend to be strongly taprooted in comparison to artificially regenerated trees, which have more of a thick branched root system (Long 1978), and bareroot seedlings have fewer laterals than naturals (Stein 1978). Differences in planting tool, initial size of seedlings, and microsite have also been suggested as possible sources of variation on root system form and tree performance (Lyon 1971, Sutton 1969, Little and Somes 1964, and Rudolf 1950).

[1]Paper presented at the Western Forest Nursery Council Conference. (Vernon, B.C., August 9-11, 1988).

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Bareroot planting stock with large root systems is especially susceptible to root deformations such as a bent or J-rooted tap root (Stein 1978). A larger sized planting hole may help the planter to keep the roots straight and vertical. Also, the planting hole shape or tree placement within the hole can effect root system form. The important question is, can planting hole size, shape, and tree placement impact the root system enough to also affect the seedling survival and growth?

The standard U.S.D.A. Forest Service practice in the Intermountain Region is to plant a tree in the center of a 4-inch straight-sided hole, augured to a depth sufficient to accommodate the full length of the seedling's root system. In this study we varied the planting hole size, shape, and the placement of the tree to observe the effects on bareroot ponderosa pine seedling survival and growth. The objectives of the study were:

1. To determine if tree survival and growth is greater in 6-inch auger holes than in 4-inch holes.

2. To determine if survival and growth differ between side-hole and center-hole planted trees.

3. To determine if a beveled planting hole results in better tree survival and growth than straight-sided holes.

METHODS

The study was installed on the Mountain Home Ranger District of the Boise National Forest. In mid May 1983, bareroot 2-0 ponderosa pine seedlings were planted on a Pseudotsuga menziesii/Carex geyeri habitat type (PSME/CAGE; Douglas-fir/Elksedge) (Steele and others 1981) at about 4,900 ft of elevation. The soil is a clay-loam of basaltic origin. The site has an easterly aspect and a slope of 10 to 20 percent. Seedling root systems were 12 inches in length. Experienced planters planted the trees in the middle of 2- by 2-ft hand scalps.

Planting holes were drilled using one of three auger bits. Two of them made cylindrical holes with 4- and 6- inch diameters. The third bit tapered from 8 inches at the top to 4 inches at the bottom and was developed at Lucky Peak Nursery near Boise, ID. Figure 1 explains the five treatments which were randomly arranged in each of 10 blocks.

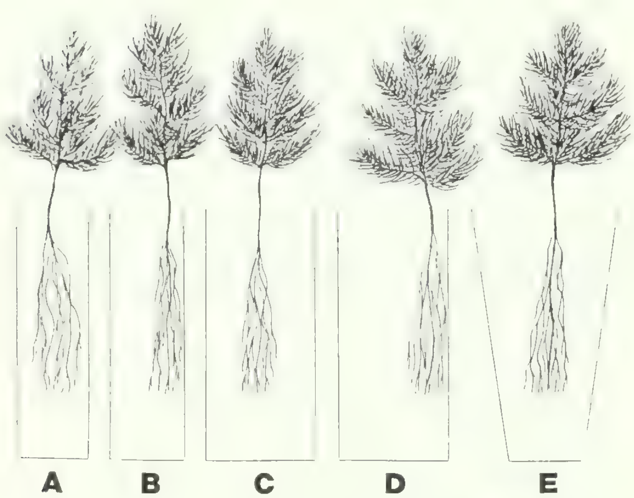

Figure 1.--Five planting hole configurations: (A) 4-inch straight-sided with tree placement in the center, (B) 4-inch straight-sided hole with tree placement on the side, (C) 6-inch straight-sided hole with tree placement in the center, (D) 6-inch straight-sided hole with tree placement on the side, and (E) 8-inch hole tapering to 4 inches at the bottom, with tree placement in the center.

Each treatment consisted of a row of 10-trees. Planting spots were 6 feet apart between rows and within rows, and planting holes were augered to a 14-inch depth. The times required to auger and plant each row were recorded during plot establishment. Survival and total height of each tree were measured after planting and then after the first, second, third, and fifth growing seasons. Finally, after 5 years of growth, several trees from each treatment were excavated to examine the root systems.

RESULTS AND DISCUSSION

Mean fifth-year survival of seedlings planted in the tapered holes was higher (α = .05) than in the 4-inch hole with side placement, the 6-inch hole with the side placement, and the 6-inch hole with center placement (table 1 and fig. 2). Survival of the seedlings planted in the 4-inch hole with center placement was intermediate. After five growing seasons, mean heights are close for all five treatments (table 1).

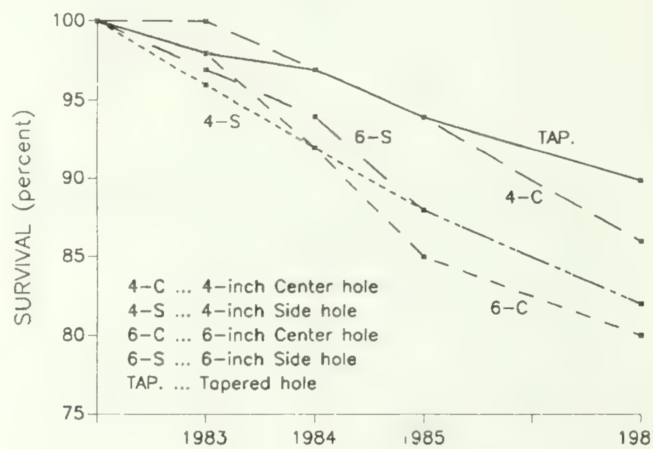

Figure 2.--Five-year survival of ponderosa pine seedlings in planting holes of different configuration. Based on first, second, third, and fifth year measurements.

These results are comparable to Buchanan's (1974) study in which after two growing seasons he found no difference in survival between ponderosa pine planted in the center of the hole and planted on the side of the hole. Little and Somes (1964) saw that center-hole planting of southern pines resulted in more spreading root systems than did slit planting. However, they still frequently found the roots of the center-hole seedlings to be in a single plane, and often the taproots were deformed.

After five growing seasons since planting, the shapes of the root systems tended to be similar within each treatment but varied between treatments. Generally, we found the straightest taproots on the trees that were

Table 1.--Mean auger and planting times per 10-tree row and fifth-year seedling mean heights and survival. Values followed by the same letter are not significantly different at the 95 percent level of confidence

Auger hole sizes (inches)	Tree placement	Augering time (sec)	Planting time (sec)	5th year height (cm)	5th year survival (percent)
4	Centerhole	45.6 a	195.1 b	57.3	86 ab
4	Sidehole	45.2 a	154.9 a	57.7	82 a
6	Centerhole	87.7 b	255.3 d	59.3	80 a
6	Sidehole	96.0 bc	191.5 b	57.0	82 a
4 - 8	Centerhole	81.8 b	232.2 c	62.2	90 b

planted on the side of the planting hole (fig. 3). However, the root systems of the side-hole trees have tended to remain in a single plane. The center-hole planted trees had root systems that spread more in all directions, but most had a slight bend in the taproot (fig. 4).

Overall, the trees planted in the tapered holes produced a spreading bell-shaped root system (fig. 4) with the most laterals of any treatment, but it is still much different from that of a seeded-in-place tree. The center-placed root systems in the straight-sided holes were also bell shaped, but most of the roots were directed downward. The planting hole size did not seem to affect the root system size, shape, or symmetry.

How these initial differences in root system morphologies will influence future growth and survival of the stand is unclear. However, none of these deformations are considered serious. I expect normal tree growth and development.

Several investigators have studied root deformations. Greene (1978) found that once established, root deformities tend to persist, but in time, root systems can partially mend themselves. Chavasse (1978) states that it is difficult to satisfactorily distribute roots during normal planting operations. Eis (1978) reported that the lifetime configuration of a root system is established early, and Long (1978) found that differences due to cultural practices were evident after 4 to 7 years. In contrast, Van Eerden (1982) reported that some deformed root systems repair themselves in time and increasingly acquire a normal or natural growth habit. According to Bibelriether (1966), this takes about 30 to 40 years. While Long (1978) found a weak correlation between root system deformation and tree growth, others found little evidence to connect them.

The 4-inch planting hole took less time to auger than the other holes (table 1). The 6-inch holes took twice as long as the 4-inch holes to auger. Tapered holes were slightly faster than the 6-inch holes. Side-hole planting went faster than center-hole planting and the 4-inch holes took less time to plant than the 6-inch and tapered holes.

Total planting time consisted of the time it takes to auger the hole plus the time to plant the tree. Of the five treatments, the 4-inch hole with the tree placed on the side was the fastest (fig. 5). The next fastest treatment was the 4-inch hole with center placement. Planting times for the center-placed trees in the 4-inch hole and the side hole placement in the 6-inch holes were very close, but because augering of the 6-inch hole took longer, total time was shorter for the 4-inch center treatment. Finally, the 8-inch hole, tapering to 4 inches, had a total planting time that was only less than the treatment with a 6-inch hole and center placement of the tree.

SUMMARY

Of the five treatments studied, the seedlings planted in the tapered holes survived best. Neither the size or shape of the planting hole, nor the tree placement influenced height growth in the first five growing seasons.

Side-hole placement tended to cause a flattened root system on one side, but all had straight tap roots after five growing seasons.

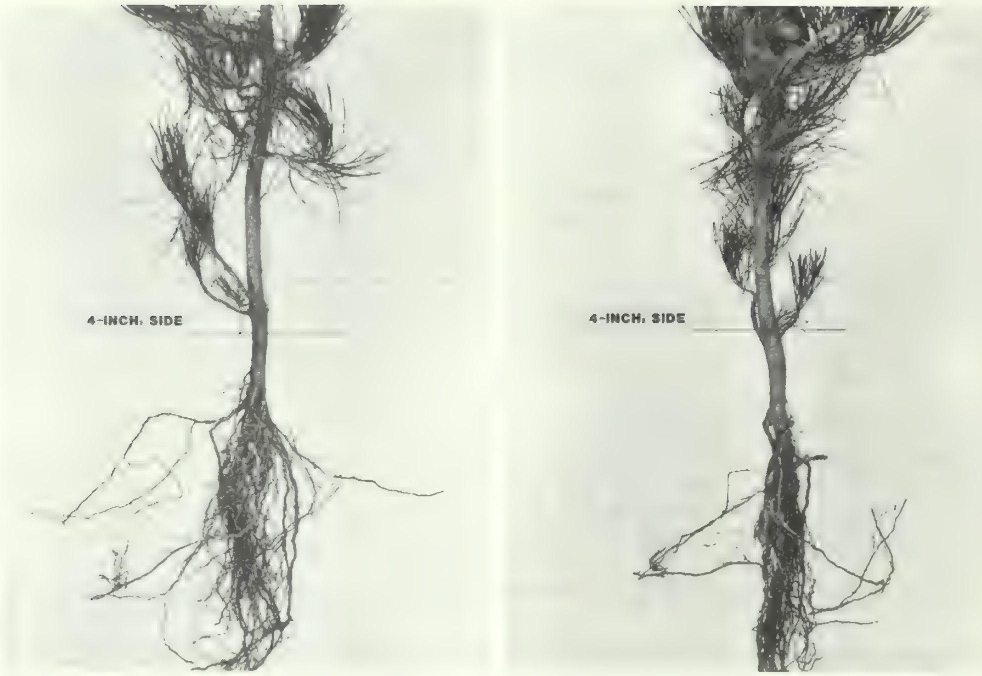

Figure 3.--A representative seedling root system that was excavated after five growing seasons. The two photos are of the same tree that was planted in the side-hole fashion. The root system in the second photo is rotated 90 degrees from the first and illustrates the somewhat flattened configuration of side-hole planted trees.

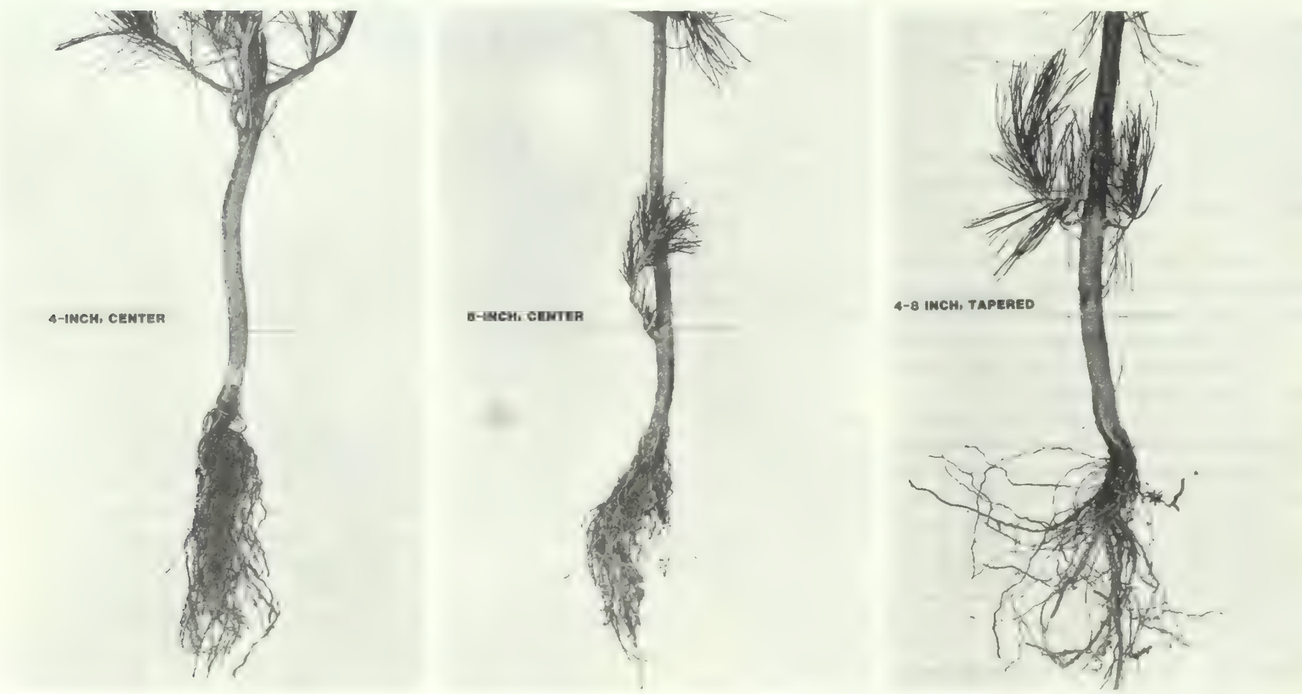

Figure 4.--These are representative seedling root systems that were excavated after five growing seasons. All three trees were planted in the center of the planting hole. The root system on the left came from a 4-inch hole, the one in the center came from a 6-inch hole, and the seedling on the right was planted in a 4- to 8-inch tapered hole.

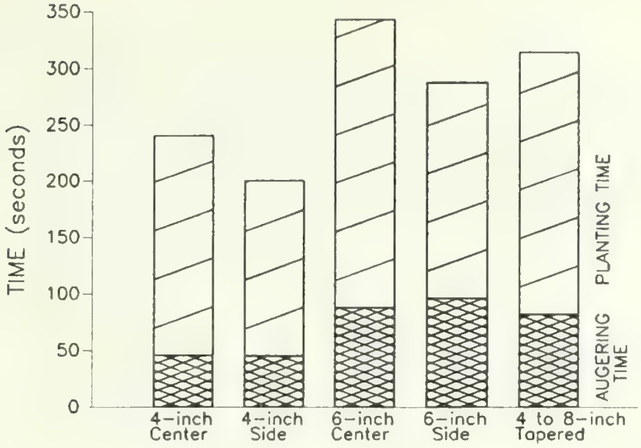

Figure 5.--Planting times required to drill holes and plant ponderosa pine seedlings in 4-, 6-, or 4- to 8-inch holes with tree placement either in the center or on the side.

Seedlings planted in the center of the hole often still had a bend in their taproot 5 years after planting. Overall, trees in tapered planting holes had the most spreading root systems. Seedlings in the center of straight-sided holes had the most fibrous root systems, but most of them were directed downward. Differences in root form are not expected to affect future height growth.

Large planting holes took longer to auger. Seedling placement on the side of the planting hole was quicker than planting in the center.

Applicablity of the results presented here may vary depending on the size of the planting stock, site quality, and especially soil type.

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Field Measurement of Photosynthetically Active Radiation[1]

D.A. Draper,[2] D.L. Spittlehouse,[2] W.D. Binder,[2] and T. Letchford[3]

Abstract.- Site preparation treatments reducing competing vegetation achieved adequate light levels for white spruce photosynthesis but did not alleviate limiting root zone soil temperature. Mechanical treatments which disturb site humus layers increased both light availability and soil temperature and resulted in increased growth performance over a 5 year period. Increased depth of mineral capping on inverted organic mounds significantly increased seedling growth performance.

INTRODUCTION

Intensity of radiation exerts a direct effect upon plant photosynthesis and morphogenesis, and an indirect effect due to environmental heating. In selecting site preparation treatments it is important to identify factors limiting growth on the site (Cleary and Kelpsas 1981, Draper 1982), and to assess the extent to which the treatment has been successful in reducing these biological stresses. On sites with well developed competitive vegetation, the relative importance of increased radiation to the seedling for driving the light reaction in photosynthesis, and the role of radiation in increased environmental heating, following a site preparation treatment, is often unclear. Field investigations are seldom able to separate the combined effect of most site preparation treatments. However, an understanding of this is important in developing and selecting treatments which promote seedling survival and growth in the regeneration time frame.

In this study the direct effects of site preparation treatment on photosynthetically active radiation ([PAR], 400 - 700 nm wavelengths) at seedling height was measured for two growing seasons following treatment, and interpreted in terms of light compensation and saturation thresholds determined for spruce (Picea glauca (Moench) Voss) seedlings in the field. Subsequent five year seedling height and ground-line diameter growth data are also presented for these treatments. The short term response of radiation and soil temperature to serial vegetation clipping, and combined vegetation and organic layer removal to mineral soil, are presented for the same site. Comparative soil temperature data from a wide range of site preparation strategies on adjacent sites are presented as well.

SITE DESCRIPTION

A north-east aspect, slope of the Bowron River Valley (Lat. 53° 40' N, Long. 121° 40' W) in the central interior of British Columbia was selected for study. The site is within the Rocky Mountain Subzone (f) of the sub boreal spruce zone[4]. Prior to treatment, abundant herb and brush species (0.85 - 1.20 m average height) combined to present severe vegetation competition. Soils on the site are gleyed, grey luvisols (Can. Soil Survey Com. 1978) characterized by mottling. The area's continental climate (mean January and July air temperatures -12 and 15° C, respectively) and site history under a 200-300 year-old mature spruce and alpine fir forest canopy, have resulted in development of a thick (0.10 - 0.25 m) mor humus layer. This organic layer remained largely undisturbed following winter logging in 1982.

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[1] Poster presented at the Combined Western Forest Nursery Council, Forest Nursery Association of B.C. and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, B.C.

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SITE PREPARATION AND PLANTING

A Bräcke cultivator equipped with Robur Maskin A-B's Högläggare mounding attachment behind a D7E prime mover was used to create inverted organic mats in August 1983. The mounder shovels were disengaged throughout, resulting in inversion of 0.3 by 0.4 m patches of consolidated organic material over undisturbed organic material. Manual additions of 0.0, 0.06, 0.12 and 0.24 m depth cappings of B horizon mineral soil were carried out to create a depth of capping range referred to as the organic mat and mineral mound treatments, respectively. Control (not mechanically prepared) areas were also established as part of the trial design. Bare root 2+1 white spruce (B.C. Forest Service Registered Seedlot 4093) were planted on all site preparation treatments between May 30 and June 15, 1984. Seedlings were centered on prepared organic mats and mounds, and planted within a screef to mineral soil on the control treatment.

A wide range of site preparation treatments were established on adjacent areas for further comparison. These were an operational prescribed fire treatment (burned August 1983); a broadcast herbicide application (0.8 m radius plot, Roundup [glyphosate] at 2.25 kg a.i.$\cdot$ha^{-1} on August 5, 1983); a blade scarification treatment (organic layers scalped to bare mineral soil on August 1983); and, broadcast herbicide treatment combined with inverted organic, mineral mounds (0.30 m depth of capping on inverted organic patches in August 1983).

MEASUREMENTS

Measurements were made of diurnal PAR patterns on 5 replicates of seedling pairs (control and 0.24 m mound treatment, 1984) and triplets (control, organic mat, and 0.24 m mounds, 1985) using Li-Cor 190SB cosine corrected quantum sensors, interrogated every 60 seconds and integrated and recorded every 30 minutes. Treatment sensors were levelled at predetermined mean seedling height of 0.36 m (1984) and 0.44 m (1985), while a background sensor was maintained above competing vegetation (1.5 m). The replicate pairs or triplets were sampled sequentially (between July 18 and October 16, 1984, and June 9 and September 17, 1985) in 14-21 day cycles to provide treatment averages. Background and treatment sensor readings were made simultaneously and recorded in μE m^{-2} s^{-1}. For comparative purposes, treatment values may be expressed as a percent of background PAR rate or as mean daily radiation totals (μE m^{-2} day^{-1}).
Generalized light saturation and light compensation thresholds (600 and 100 μE m^{-2} s^{-1}, respectively) were determined for these white spruce seedlings in the field using a Li-6000 portable photosynthesis apparatus (Draper et al. 1985). Mean seedling height and ground-line diameter were measured at time of planting and at the end of the first through fifth growing seasons on all treatments.

A single, 1.26 m radius, clipping plot was established in a representative complex of lady fern, fireweed and false hellebore (0.90 m height) and instrumented with 3 replicated thermistor-type soil temperature sensors (0.05 m depth in mineral soil), and a quantum sensor leveled at 0.15 m at plot centre. In an immediately adjacent area, left untreated, a further 3 soil temperature sensors and a background (1.5 m) PAR sensor were installed. Daily mean, minimum and maximum soil temperatures were calculated from 30 minute averages and recorded. Plot vegetation was serially clipped and removed on August 15, 19, 22 and 27 reducing plot leaf area from 100% to 0%. Clipped leaf area was measured with a Li-Cor 3100 leaf area meter and expressed as a percentage of total plot leaf area. Following removal of all competing vegetation the plot was manually scalped on September 8, to bare the mineral soil surface.

A series of soil temperature sensors were installed in alternative site preparation treatments on site including a control treatment, prescribed fire, blade scarification, organic mat inversion (Bräcke patch scarification), mounding treatments with differing levels of capping, broadcast herbicide treatment, and broadcast herbicide in combination with mounding. A manual (1200 - 1400 h) measurement was made of 4 replicate thermistors in the 1985 growing season, and, for comparative purposes the data expressed as a percentage of the measured control treatment temperature.

RESULTS

Figure 1 shows a typical diurnal PAR trace on a clear July day as received above the vegetation (background), and at seedling height in the control and mounded treatments. The mineral mound treatment received nearly all measured background radiation with the exception of low sun-angle periods (0500-0900 and 1700-2100 h PDST). The control treatment trace is strongly affected by vegetation interception, resulting in an irregular sun-fleck pattern over most of the lighted part of the day. Rate of PAR on the mound treatment is nearly that of background at mid-day, but control PAR rate is much reduced compared to background.

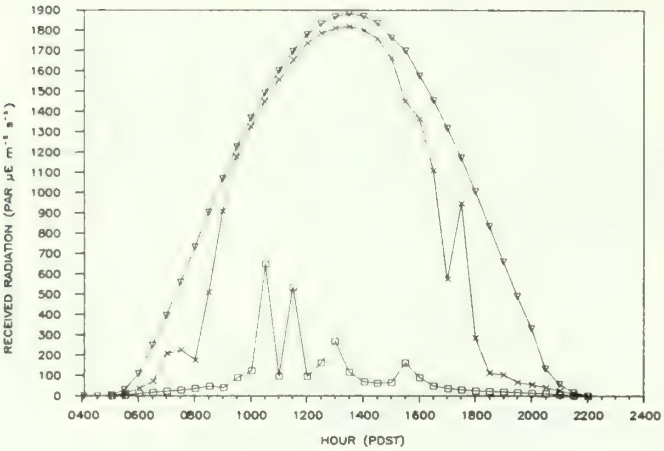

Figure 1.--Typical diurnal PAR pattern on a clear July day in 1984 one year after site preparation. Background sensor above competing vegetation (▽) at 1.5 m height, control (□) and mineral mound treatment (x) sensors at seedling height (0.36 m).

Daily treatment PAR patterns, averaged over the 1984 growing season, are shown in Figure 2 with light compensation and saturation thresholds overlain. Values plotted are the mean half hourly rate of replicated samples between July 18 and October 16, 1984. One year following site preparation, mounded seedlings received approximately 70% of mean total daily radiation (background). The control seedlings averaged 11% of background over the same period. Interpreted in terms of the light thresholds, mounded seedlings received 66% of available PAR between 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ and were above compensation threshold for 10-11 hours a day. Control seedlings, by contrast, averaged 15% of background total radiation between 100 and 600 $\mu E\ m^{-2}\ s^{-1}$, and exceeded compensation thresholds for only 4-5 hours in the average day (fig. 2).

In the second growing season (1985) a combination of increased mean seedling height and a reduction in average height of competing vegetation changed the relationship of received radiation between treatments. Control, organic mat and mound treatments seasonal mean diurnal patterns are given in Figure 3. Mound treatments received 78%, the organic mat treatment 64% and the control 49% of mean daily background total PAR. Duration of exposure to PAR above compensation threshold was similar for all treatments, averaging 10-11 hours a day. Seedlings planted on organic mats received less total radiation than mounded seedlings, but similar amounts between the 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ thresholds.

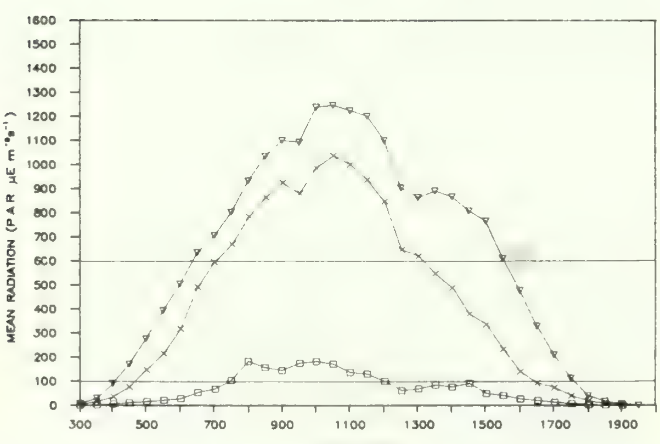

Figure 2.--Treatment mean diurnal PAR pattern during 1984 (July 18-Oct.16) growing season. Background sensor above competing vegetation (▽) at 1.5 m, control (□) and mineral mound treatment (x) sensors at seedling height (0.36 m). 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ light compensation and saturation thresholds, respectively.

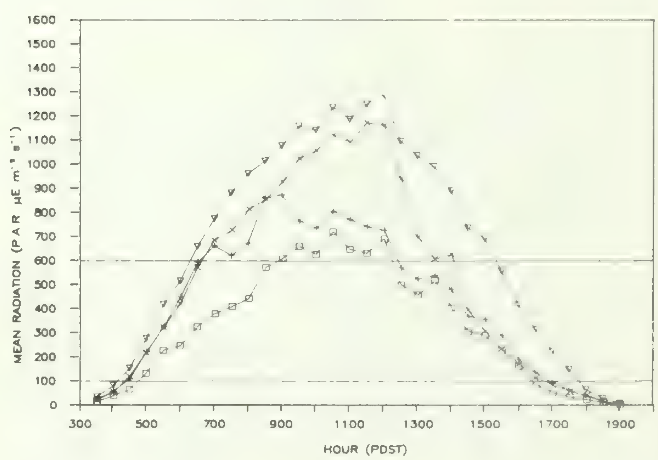

Figure 3.--Treatment mean diurnal PAR pattern during 1985 (June 9-Sept.17) growing season. Background sensor above competing vegetation (▽) at 1.5 m, control (□), inverted organic mat (+) and mineral mound treatment (x) sensors at seedling height (0.44 m). 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ light compensation and saturation thresholds, respectively.

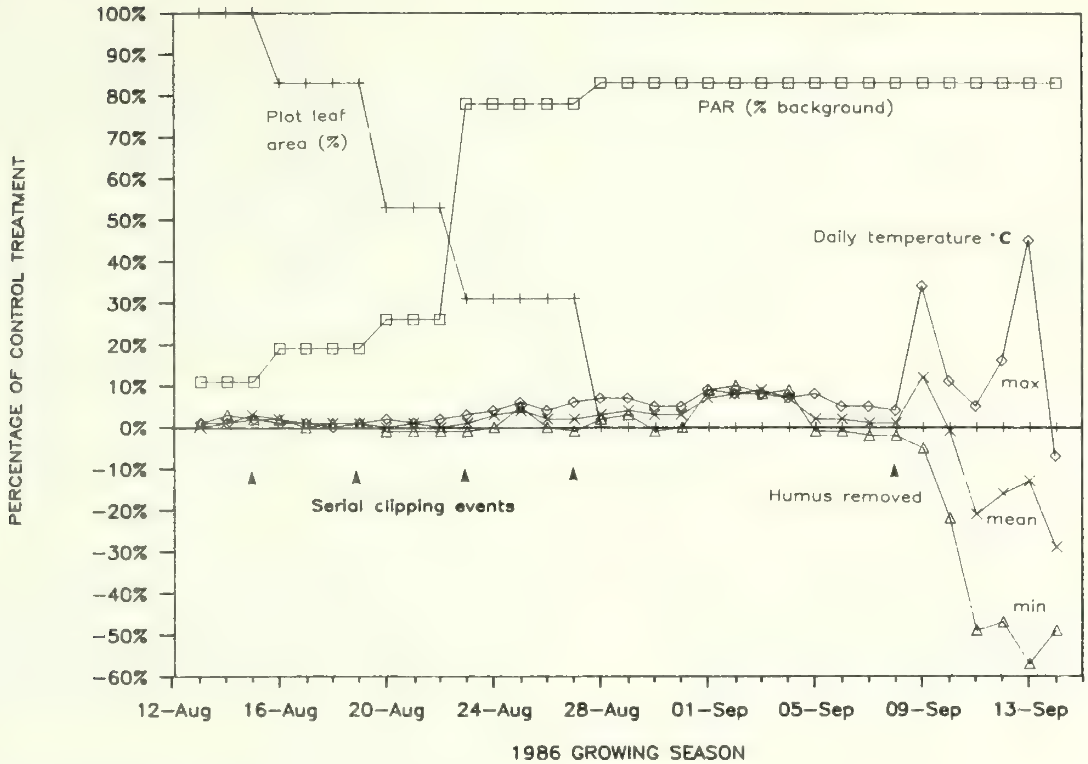

Figure 4.--Short term response of received radiation at seedling height and soil temperature (0.05 m depth) to reductions in vegetative cover. Seedling radiation (□) expressed as a % of background (1.5 m) radiation, and daily minimum (△), maximum (◇) and mean (X) mineral soil temperature (0.05 m depth) as a % of control (untreated) soil temperature. Leaf area reductions (+) on August 15, 19, 22, 27 expressed as a % of plot total leaf area.

The effect of incoming PAR on short term soil temperature characteristics was assessed by serially reducing the vegetative cover of a 1.26 m radius plot and measuring changes in received PAR and soil temperature (fig. 4). Prior to first treatment (August 15) radiation beneath the undisturbed competing vegetation canopy averaged 11% of background daily totals. In the same period, daily soil temperature averages in the treatment plot exceeded those of the adjacent control by about 1%, or 0.1° C above the control average of 10° C. PAR response to vegetation removal, averaged over the post clipping period, was immediate (fig. 4). Removal of up to 50% plot leaf area increased received radiation at 0.15 m height from an average of 11% to only 26% of background. The next vegetation removal, from 50% to 30% plot leaf area, resulted in a large increase in received PAR from 26% to 80%. Subsequent removal of the remaining 20% plot leaf area had little effect on received radiation percent (fig. 4). The difference between plot PAR after August 28 (100% leaf area removed) and background PAR is attributed to plot edge effects at low sun angles (see fig.2 and 3).

Daily soil temperature at 0.05 m depth in the mineral soil, beneath a 0.20 m consolidated mor humus, did not respond greatly to level of vegetation clipping, or total vegetation removal (fig. 4) over the period considered. Effects have not been masked by considering average daily mean, minimums and maximums as the half hourly trends collected (not presented) did not show a consistent response to clipping treatments either. Maximum increases in mean daily soil temperature over the 12 day period following vegetation removal were 9%, or less than 1° C, greater than the 10° C control soil temperature recorded (fig. 4), and followed a 4 day period of high radiation.

Scalping the organic layer to expose mineral soil (September 8) had an immediate and relatively large effect on soil temperature (fig.4). Daily mean, maximum and minimum temperatures were directly driven by ambient air temperature (not shown). Scalped plot maximum daily temperatures exceeded control maximums (7.5° C) by 3° C, and minimum temperatures were as much as 4° C below the recorded control daily minimum of 6.5° C.

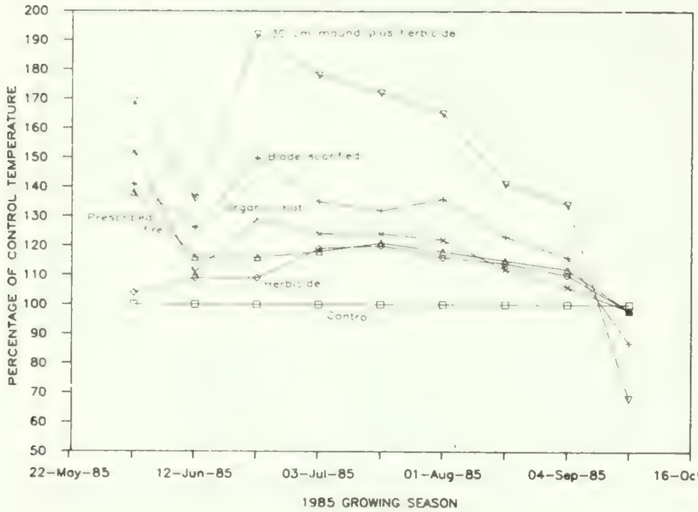

Figure 5.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values expressed as a % of control (untreated) soil temperatures.

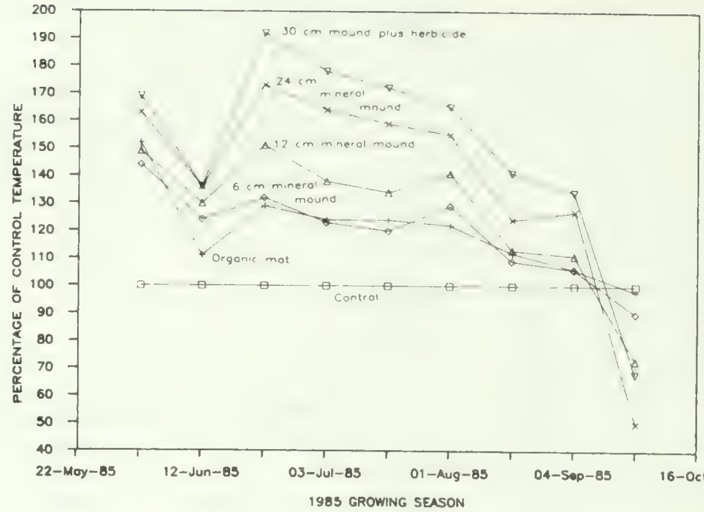

Figure 6.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values are expressed as a % of control (untreated) soil temperatures.

Data presented in Figure 4 is corroborated by the general temperature response measured over a wide range of site preparation treatments. Highest mid-day mineral soil temperatures (0.10 m depth) were recorded on site preparation treatments which remove or invert the organic layer (fig. 5). Neither prescribed fire treatment (which blackened and reduced but did not totally consume the organic layer), or the herbicide treatment (which effectively controlled competing vegetation to less than 30% total cover) were as effective at increasing mid-day soil temperatures as mechanical treatments. Within the range of inverted organic mat and mounding treatments tested (fig. 6) there was a consistent increase in soil temperature associated with increased depth of mineral capping. Seasonal average control temperatures in Figure 6 ranged from 6° C in late May to 10° C in August. Large mineral mound soil mid-day temperature averaged 15° C over the same period. Reduction of the vegetative competition remaining after mounding by herbicide application further increased measured soil temperature as shown by the mounding plus herbicide treatment (fig. 6).

Increased depth of mineral capping on inverted organic mats resulted in increased soil temperatures and subsequent improvement in seedling growth (figs. 7 and 8). The trend to increased total height and ground line diameter with increased depth of mineral capping is consistant, and the fifth year treatment means are significantly different statistically. This corroborates observations made by McMinn[6] regarding growth performance of spruce seedlings on inverted organic mounds with differing levels of capping.

DISCUSSION

On sites with continuous, well developed organic layers site preparation should be targeted at reduction, mixing or inversion of the organic material to increase root zone soil temperatures rather than vegetation reduction to increase available light. Mechanical treatments which remove or disturb the insulating organic layers are associated both with increases in soil temperature (McMinn 1982) and adequate PAR for photosynthesis (fig. 3). Removal of vegetation alone, on sites with relatively thin humus, may result in increased soil temperature[7], but more generally, soil temperatures in the sub boreal spruce zone are too low for maximum root growth even following clear cutting (Dobbs and McMinn 1977, Draper et al. 1985).

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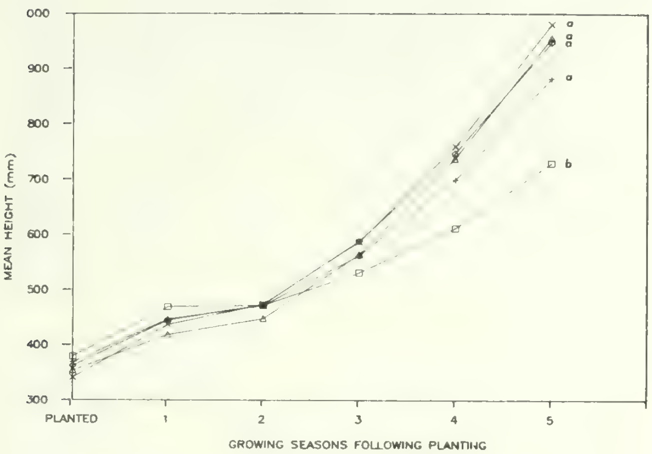

Figure 7.--Treatment mean seedling height (m) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Control (□), inverted organic mat (mat) (+), mat plus 6 cm mineral capping (◇), mat plus 12 cm mineral capping (△), organic mat plus 24 cm mineral capping (X). Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

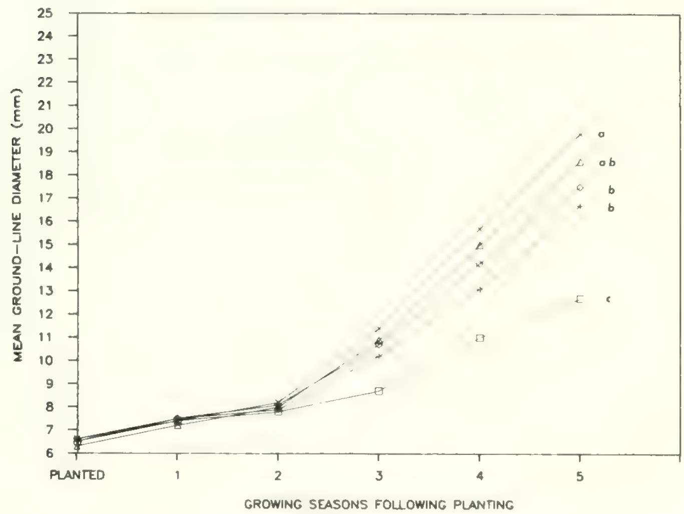

Figure 8.--Treatment mean seedling ground-line diameter (mm) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Legend as in fig. 7. Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

Removal of half the leaf area of a 100% cover lady fern association increased received radiation at seedling level from 11% to only 25% of the above canopy background. Significant radiation increases, to well over seedling saturation thresholds, were measured with removal of about 70% of plot leaf area. The advantages of further vegetation reduction are slight in terms of radiation required to drive photosynthesis and measured increased mineral soil temperature (fig. 4) unless the *in situ* humus is disturbed.

CONCLUSIONS

Identification of the specific biological limitations to seedling growth under field conditions is very difficult, both empirically and experimentally. The relationships of measured light and soil temperature availability to planted seedlings, in response to site preparation strategies, suggest that soil temperatures rather than available light is limiting in the area of the sub boreal spruce zone considered in this experiment. Operational site preparation treatments targeted on organic layer removal or inversion provide both increased soil temperature and, at least temporarily, reductions in competitive vegetation, which result in above average fifth year seedling growth.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-168**

A Screening Procedure to Evaluate Air Pollution Effects on Class I Wilderness Areas

Douglas G. Fox, Ann M. Bartuska,
James G. Byrne, Ellis Cowling,
Richard Fisher, Gene E. Likens,
Steven E. Lindberg, Rick A. Linthurst,
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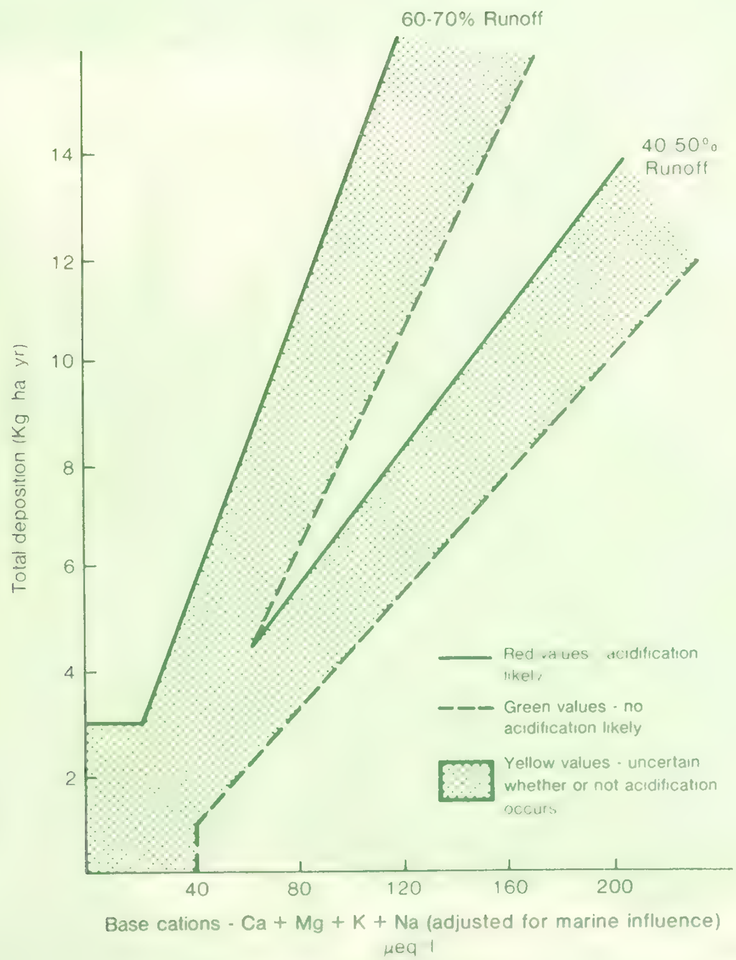

Fox, Douglas G.; Bartuska, Ann M.; Byrne, James G.; and others. 1989. A screening procedure to evaluate air pollution effects on Class I wilderness areas. Gen. Tech. Rep. RM-168. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

This screening procedure is intended to help wilderness managers conduct "adverse impact determinations" as part of Prevention of Significant Deterioration (PSD) applications for sources that emit air pollutants that might impact Class I wildernesses. The process provides an initial estimate of susceptibility to critical loadings for sulfur, nitrogen, and ozone. It also provides a basis for requesting necessary additional information where potential adverse impacts are identified.

Keywords: Prevention of Significant Deterioration, air pollution

On the Cover:

Foreground: The screening graph for determining effects of atmospheric deposition on aquatic ecosystems (fig. 1, page 6). Background: West Glacier Lake, part of the Glacier Lakes Ecosystem Experiments Site (GLEES), a high-elevation area that, while not a designated wilderness, is being used for research to quantify atmospheric effects on wilderness. GLEES is instrumented for meteorological, aerometric, deposition, snowmelt, and streamflow measurements as part of a holistic ecosystem monitoring program conducted by the air polution research unit at the Rocky Mountain Station. GLEES is located on the Medicine Bow National Forest, approximately 15 km west of Centennial, Wyoming, in the Snowy Range Mountains.

USDA Forest Service
General Technical Report RM-168

January, 1989

A Screening Procedure to Evaluate Air Pollution Effects on Class I Wilderness Areas

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[1] Rocky Mountain Forest and Range Experiment Station. The Station's headquarters is in Fort Collins, in cooperation with Colorado State University. Supervision was provided by Douglas G. Fox, Chief Meteorologist and Project Leader for The Research Work Unit, Effects of Atmospheric Deposition on Natural Ecosystems in the Western United States.

Contents

PREFACE

A group of scientists and land managers held a cooperative workshop to help the Forest Service develop a screening process for evaluating Prevention of Significant Deterioration (PSD) applications for sources that might impact Class I area wildernesses. The process described in this document provides an initial estimate of the susceptibility of different Class I areas to critical loadings for sulfur, nitrogen, and ozone. Results should help Forest Service land managers when conducting "adverse impact determinations" of PSD permit applications and provide a ready basis for requesting necessary additional information where potential adverse impacts are identified.

This document was prepared by the authors and participants at the Workshop on Air Pollution Effects on Wilderness, held May 2-5, 1988, at the Institute of Ecosystem Studies, Millbrook, New York.

ACKNOWLEDGMENTS

Dr. Gene Likens and his co-workers at the Institute of Ecosystems Studies, New York Botanical Gardens, hosted the workshop at the Mary Flagler Cary Arboretum in Millbrook, NY. The participants at the May 1988 meeting in Millbrook developed the concept of this document, and the authors wrote the first draft. All the participants reviewed a second draft. A final step involved the review of 8 scientific peers who were not at the meeting, but by virtue of both their research and their positions with government, industry, and interested groups, were able to substantially improve the document. Finally, scientists at the Rocky Mountain Station conducting research on effects of atmospheric deposition on natural ecosystems, particularly Frank Vertucci, Robert Musselman, and Anna Schoettle added significantly to the final report by evaluating and incorporating reviewers' comments, correcting references, and providing the benefit of their substantial knowledge and experience to the final report.

USER NOTES

When implementing the PSD review process, line officers and staff must understand the assumptions and variables used to construct the screening model. The model will help in PSD review only if the assumptions and logic involved are fully understood. It is critical that the user recognize the development methodologies and limitations. For instance, participating scientists and managers agreed on similar numerical loadings for a pollutant in seemingly different Class I areas. This agreement resulted because similarly sensitive ecosystems occur in many different Class I areas, although not to the same extent. For example, alpine is the dominant ecosystem in Alpine Lakes Wilderness in northern Washington, but a minor portion of the San Gorgonio Wilderness in southern California. However, the loading values for these two wildernesses are the same because the alpine ecosystem was considered most sensitive, and the loadings were established to protect the most sensitive ecosystems.

It should also be recognized that the loadings suggested by this screening technique are likely to overestimate potential impacts. As such, they may be applicable for PSD permit review of effects on designated Class I air quality areas, but are not intended to suggest target loadings on ecosystems in general.

Users should recognize that this document represents the state of understanding in Spring 1988. Science is very productive in this field, and it is anticipated that this document will be upgraded periodically.

A Screening Procedure to Evaluate Air Pollution Effects on Class I Wilderness Areas

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INTRODUCTION

Forest Service land managers need information about the effects of air pollution on wilderness areas that have been formally designated as Class I by the Clean Air act (Public Law 95-95). Managers of Class I areas are responsible for the review of preconstruction applications termed "Prevention of Significant Deterioration" (PSD) permits. Forest Service managers must review PSD permits for major new emission sources (more than 100 tons of a pollutant per year) or the modification of an existing source that may cause possible effects on Class I areas.

This introductory section describes a workshop of Forest Service management leaders and prominent scientists studying the biological effects of air pollution and acid deposition. They worked together to identify how best to merge the current state of science with needs of Class I area managers. (Work group participants are also identified.) It then briefly describes Forest Service responsibilities under the Clean Air Act and the Wilderness Act.

The second section summarizes the major results of the workshop. Results are stated as proposed maximum acceptable pollutant loadings on specific ecosystems. These maximum loadings are intended for use by federal land managers screening PSD permits. The proposed screening process suggests one of three decisions: recommend permit approval (new pollutants will lead to loadings below Green Line), recommend permit denial (new pollutants will lead to loadings above Red line), and an intermediate zone (Yellow Zone), where more data are needed before deciding on a course of action.

The screening concept uses numerical values of sulfur and nitrogen deposition and ozone concentrations in nine different wildernesses considered representative of the diversity of wilderness ecosystems.

The third and fourth sections provide detailed explanations, justifications, and cautions regarding the screening approach as applicable to aquatic and terrestrial ecosystems in wilderness landscapes.

Workshop Organization and Participants

A partnership between scientists and managers is needed to protect air-quality-related values in Class I area wildernesses. The form of such a partnership was developed and approved by some 70 distinguished scientists at the 1987 Cary Conference,[2] which focused on long-term studies of ecosystems:

"Ecological understanding is required to develop environmental policies and to manage resources for the benefit of humankind. Sustained ecological research is one of the essential approaches for developing this understanding, and for predicting the effects of human activities on ecological processes. Sustained research is especially important for understanding ecological processes that vary over long periods of time. However, to fulfill its promise, sustained ecological research requires a new commitment on the part of both management agencies and research institutions. This new commitment should include longer funding cycles, new sources of funding, and increased emphasis and support from academic and research institutions. Because they have common long-term goals, we propose a new partnership between scientists and resource managers. Elements of this partnership include:

1. Agreement by scientists to answer the questions asked by managers, while making clear the level of uncertainty that exists and what additional research needs to be done.

[2]Statement adopted at the Cary Conference in Millbrook, New York, on May 13, 1987: revised July 4, 1987 (Likens in press).

2. Agreement by managers to give serious consideration to these answers and to support the continuing research toward better answers.

Sustained ecological research supported by this new partnership can contribute significantly to the resolution of critical environmental problems."

Such partnerships are essential to use scientific information in an orderly and efficient manner for the management of complex natural resources.

Organizers of this workshop invited a group of prominent scientists, knowledgeable in the areas of effects of air pollution (sulfur and nitrogen deposition and ozone exposure) on ecosystems, to interact with a group of Forest Service managers who have air resource management responsibilities. The objectives of this workshop were to establish communication between these two groups of individuals, and to develop a screening process for evaluating PSD applications. This relationship was fostered by a 3-day workshop at the Institute of Ecosystem Studies of the New York Botanical Garden in Millbrook, New York.

The May 1988 workshop was to develop an air pollution screening process for managers of Class I areas. The participants decided that a screening process that considered only the impacts of the deposition of sulfur and nitrogen and ozone concentration on specific ecosystems would be appropriate. Other pollutants can adversely affect ecosystems, but the chosen pollutants are those most commonly of concern. Pollutant loadings are determined by using air dispersion models and estimates of deposition velocity to project the worst case deposition of S and N from proposed industrial emissions.

Four teams of scientists and managers (see table 1) were formed to determine independently the sulfur, nitrogen, and ozone values to be used in answering the following questions:

1. Below what magnitude of sulfur and nitrogen deposition and ozone concentration, resulting from proposed air pollution emissions, for each of the nine Class I area wildernesses, can a land manager have a high degree of confidence that no air-quality-related values (AQRV's) would be adversely affected?

2. Above what magnitude of sulfur and nitrogen deposition and ozone concentration for each of the nine Class I area wildernesses can a land manager have a high degree of confidence that at least one of the selected air-quality-related values would be adversely affected by the proposed air pollution emissions?

The Forest Service managers present at the Workshop picked tentative AQRV's (or reported those already developed in Forest Plans) for the selected wildernesses in their Regions. These AQRV's were then used by the teams and working groups in the development of their loading estimates. Also, each Class I area wilderness was described. Appropriate site data and first-hand knowledge were used to estimate numerical loadings and identify problems in applying these numbers to specific areas. Values were chosen to protect the current condition of the selected AQRV's in each Class I area.

Visibility is the only AQRV specifically mentioned in the Clean Air Act, and it has been determined to be an important AQRV in all class I areas except Bardwell Bay (FL) and Rainbow Lake (WI). However, this workshop did not address visibility. The scientists, known for their expertise in air pollution effects on biotic systems, were invited to this workshop to develop screening guidelines for only the terrestrial and aquatic components of the ecosystem. The absence of comments on visibility should not be construed as a judgment of its relative value compared to biotic systems. In fact, in some areas, visibility might be considered adversely affected by air pollution concentrations that were not considered adverse to the biotic systems. For more discussion of visibility, the Forest Service Air Resource Management Manual (USDA 1987) should be consulted.

Federal Land Managers' Responsibilities Concerning Protection of Class I Area Wildernesses

Wilderness Act

The Wilderness Act of 1964 (Public Law 88-557) established the National Wilderness Preservation System "to secure for the American people an enduring resource of wilderness." The Act states:

> "A wilderness... is an area where the earth and community of life are untrammeled by man, where man himself is a visitor who does not remain... Wilderness is...undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable..."

Wilderness is a distinct resource with inseparable parts. When possible, natural processes are allowed to operate within wilderness; for example, lightning-caused fires are allowed to burn under prescribed conditions. Wilderness is managed to make it as wild and natural as possible, including closing old roads, restoring damaged trails and campsites, and removing most structures. Managers use primitive tools to do the

Table 1.--Work group assignments for participants.[1]

Team 1 **Aquatic Ecosystems**

Gene E. Likens *(Chairperson)*
Peter Dillon *(Combined group chair)*
Thomas Frost
Dale W. Johnson
Dale Nichols
Ed Brannon
Tom Thompson
Bill Carothers
Dave Unger
Jay Messer *(Note Taker)*

Team 2 **Aquatic Ecosystems**

Rick A. Linthurst *(Chairperson)*
Mike Pace
Richard Wright
Steve Mealey
Mike Edrington
Gray Reynolds
Anne Fege

Richard Fisher *(Note Taker)*

Team 3 **Terrestrial Ecosystems**

Ann M. Bartuska *(Chairperson)*
Jan Nilsson
John Reuss
Bill Mattson
Steve Lindberg *(Combined group chair)*
David F Karnosky
Chuck Wildes
John Butruille
Clif Benoit
Bob Loomis
Douglas G. Fox *(Note Taker)*

Team 4 **Terrestrial Ecosystems**

Ellis Cowling *(Chairperson)*
Gary M. Lovett
Dave Peterson
J. R. N. Jeffers
Peter B. Reich
Dave Radloff
Dick Stauber
Steve Harper

James G. Byrne *(Note Taker)*

[1] *Affiliations of participants are given in appendix D.*

job. As with other National Forest resource management efforts, public involvement is sought in planning for wilderness management and use.

Many management activities and uses are prohibited in wilderness: roads, motorized equipment and mechanical transport, landing of aircraft, most commercial enterprises, and permanent structures and installations. The Wilderness Act allows certain activities within wilderness, as long as the wilderness character is preserved. These uses include livestock grazing, hunting, fishing, exercising water rights, and existing mineral claims. Special exceptions are made in some wilderness legislation that permit mineral exploration and exploitation, access to private land, maintenance and use of airstrips, and, in Alaska, native use for subsistence.

The scientific value of wilderness is recognized in the 1964 Act. A decade or a century in the future, wildernesses will serve as baseline or "control" areas, since they are managed to preserve natural conditions and generally will have been affected primarily by the forces of nature. Permission to conduct scientific studies is granted only if the studies require a wilderness environment, and cannot be accomplished outside the wilderness. Motorized equipment or mechanical transport cannot be justified on the basis of cost or efficiency, and are allowed only if a comprehensive analysis shows there are no alternatives.

Clean Air Act

The Clean Air Act (CAA) Amendments of 1977 included a program for prevention of significant deterioration of air quality, generally referred to as the "PSD" program. This PSD program is to prevent areas currently having clean air from becoming too polluted. Certain wilderness areas and National Parks established before August 1977 were designated as Class I areas. A Class I designation allows only very small increments of new pollution above already existing air pollution levels within the area. Wildernesses established since August 7, 1977, are Class II areas. Class II areas have a larger increment, which is about 25 percent of the national ambient air quality standard. Class I areas in the National Forest System are identified in figure A-1 in the appendix to this report.

The CAA charges the federal land manager (FLM) of Class I areas with an affirmative responsibility to protect the air-quality-related values (AQRV's) of these areas from adverse air pollution impacts. AQRV's are those values within the Class I area that could be affected by air pollution such that the purpose for which the area was established (biological diversity, water

quality, fish) would be adversely affected. Within the Forest Service, the Regional Forester has been delegated this affirmative responsibility. Managers must minimize the conflicting human impacts of air pollution, much as they manage other uses to limit their impacts on the wilderness resource.

The PSD program is a preconstruction review and permitting process for major new or expanding sources of pollution. Any major facility seeking a new source permit for location or expansion in a clean air area must meet several requirements: Class I and/or II increments, the AQRV impact analysis, and the Best Available Control Technology (BACT) evaluation. In the PSD permitting process, the FLM determines whether a proposed source's emissions will have an adverse impact on Class I area AQRV's.

New source permit applicants submit plans to the permitting authority, who examines the proposed location of the facility, its general design, projected air pollution emissions, and potential impacts. When a proposed source's emissions may have an impact on a Class I area, the permitting authority (EPA, or the State, if EPA has delegated PSD authority to that State) alerts the FLM. The FLM then determines the impact of the projected pollution level increases on the Class I area AQRV's and recommends approval, denial, or modification of the preconstruction permit. When the air regulatory authority certifies that a permit application is complete, the FLM might have as little as 30 days to review the permit application and respond to the regulatory authority. The FLM's determination of adverse impact must be completed within this period. This reply is included in the required public participation phase of the PSD program.

WORKSHOP RESULTS

The Green-Yellow-Red Screening Model

A conceptual framework was developed to implement the partnership between scientists and managers to help evaluate the potential impact of proposed new air pollution sources on Class I areas. This framework includes the idea of acceptable (Green Line), unacceptable (Red Line), and intermediate (Yellow Zone) levels of pollution. It is very important to keep in mind that this framework represents a screening tool. As such, it is intended to simplify the decision process by providing guidelines for general use rather than formulas for specific application. In all circumstances, the magnitude of these screening values, both Red and Green, are subject to change based on better site specific information. In the absence of such data, use of screening values should advance the evaluation of PSD permits.

Pollutant doses less than the Green Line value might be judged permissible by managers, and the application recommended for approval without additional data. Conversely, doses above the Red Line value are likely to cause at least one AQRV to be adversely affected. Thus they would result in a recommendation for denial unless additional site-specific data are provided to prove that the identified AQRV of the Class I area would not be adversely affected. Doses falling between the Green and Red Lines (the Yellow Zone) would be evaluated on the basis of additional information provided or gathered by the applicant or the USDA Forest Service.

It is prudent for the Class I manager to have AQRV's clearly identified, their current status monitored, and specific limits of impact defined. To avoid challenges, such information must be based upon or include multiyear data, and scientific peer review. Use of these screening techniques is also based on the availability of accurate deposition and concentration data at or near the Class I areas. These data also should be quality assured. Suggestions from long-term sustained ecological research will be useful in this context.

Specifically, the Green Line denotes a total loading (current deposition plus predicted additional deposition from the new source) of sulfur and nitrogen and the total dose of ozone that predicts, with a very high degree of certainty, that no AQRV will be adversely affected. The Red Line denotes a total loading of sulfur and nitrogen and the total dose of ozone that predicts, with a very high degree of certainty, that at least one AQRV will be adversely affected. Sustained ecological research, part of the partnership between managers and scientists, will refine and modify these decision points with new or better data.

Participants agreed that Green and Red Line numbers need to be ecosystem-specific. The selected numbers reflect the effects of pollutants on the AQRV's identified within the nine example Class I areas. Terrestrial and aquatic systems were considered separately because the understanding of combined impacts is not sufficiently developed to set numerical levels. Ozone was considered only to affect terrestrial

ecosystems. Aquatic impacts were estimated by the sensitivity of surface waters as measured by the combined concentrations of calcium, magnesium, potassium, and sodium (corrected for marine influences) expressed in microequivalents per liter (µeq/l). Green and Red Line values for aquatic impacts are presented graphically.

Terrestrial Green and Red Line Screening Numbers

Participating scientists familiar (to varying degrees) vith detailed data applicable to these Class I area vildernesses agreed to the values in table 2. The Green Line represents the total pollution loadings (current plus proposed new source contribution) pollution loadings *below* which a land manager can recommend a permit be issued for a new source unless data are available to indicate otherwise. The Red Line represents an estimate of the total pollutant loadings that each wilderness can tolerate. Total loadings *above* these values suggest the land manager recommend reduction of emissions from a new source unless data are available to indicate that no AQRV of the Class I area is likely to be adversely affected.

Pollutant loadings *between* these values require the gathering of enough valid data to determine whether or not a permit for a new source should be recommended. General ideas for dealing with loadings that fall between the values are described in the next section.

Aquatic Green and Red Line Screening Graph

Green and Red Line screening values associated with effects on aquatic ecosystems are most appropriately displayed graphically. The sensitivity of aquatic ecosystems to S and N deposition is measured by their acid-neutralizing capacity (ANC). The ANC may already be reduced, however, in systems subjected to significant deposition loading. A good measure of sensitivity for fresh surface waters is the sum of the concentrations of base cations (calcium, magnesium, potassium and sodium ions) in the water. Since Class I areas contain a diversity of lakes and streams, the participants felt that Green and Red Line values should be presented as a function of the ion concentration. The manager will need loadings based on knowledge of the surface waters in the Class I area as well as the deposition environment.

The graph for aquatic systems shows Green and Red Line values with total deposition loading (in kg of S/ha-yr) on the vertical axis and concentration of (nonmarine) Ca+Mg+K+Na (in µeq/l) on the horizontal axis. The significance of these concentrations is based on the relative amount of water that is exported from the watershed. Green and Red Line values are presented in figure 1 for runoff estimated to be about 60-70% of the precipitation, and for 40-50% runoff. Green and Red Line values for additional runoff percentages are presented in appendix C in figures C-1 and C-2.

Table 2.--Terrestrial Green and Red Line screening values.

Wilderness area[1]	Nitrogen deposition[2] Green Ln	Red Line	Sulfur deposition Green Ln	Red Line	Ozone concentration[3] Green Ln	Red Ln
	-----*kg N/ha-y*----		---*kg S/ha-y*----		------------*ppb*----- ------	
Alpine Lakes, WA	5-7	15	3-5	20	35/75	55/110
Hoover, CA	3-5	10	3-5	20	35/75	55/110
San Gorgonio, CA	5	15	3-5	20	35/75	55/110
Bob Marshall, MT	3-5	10-15	5	20	35/75	55/110
Bridger, WY	3-5	10	5	20	35/75	55/110
Superstition, AZ	3-5	15	5-7	20	35/75	55/110
Joyce Kilmer, NC/Slick Rock, TN	7-10	15	5-7	20	35/75	55/110
Otter Creek, WV	7	10-15	5	20	35/75	55/110
Boundary Waters Canoe Area, MN	3-5	10	5	20	35/75	55/110

[1]*See appendix B for description of wildernesses.*

[2]*Nitrogen and sulfur deposition are total values including all forms, wet, dry, NH_4-N and NO_x-N, SO_4-S, SO_2-S, etc.*

[3]*Growing season average/second highest 1 hour average value in a year.*

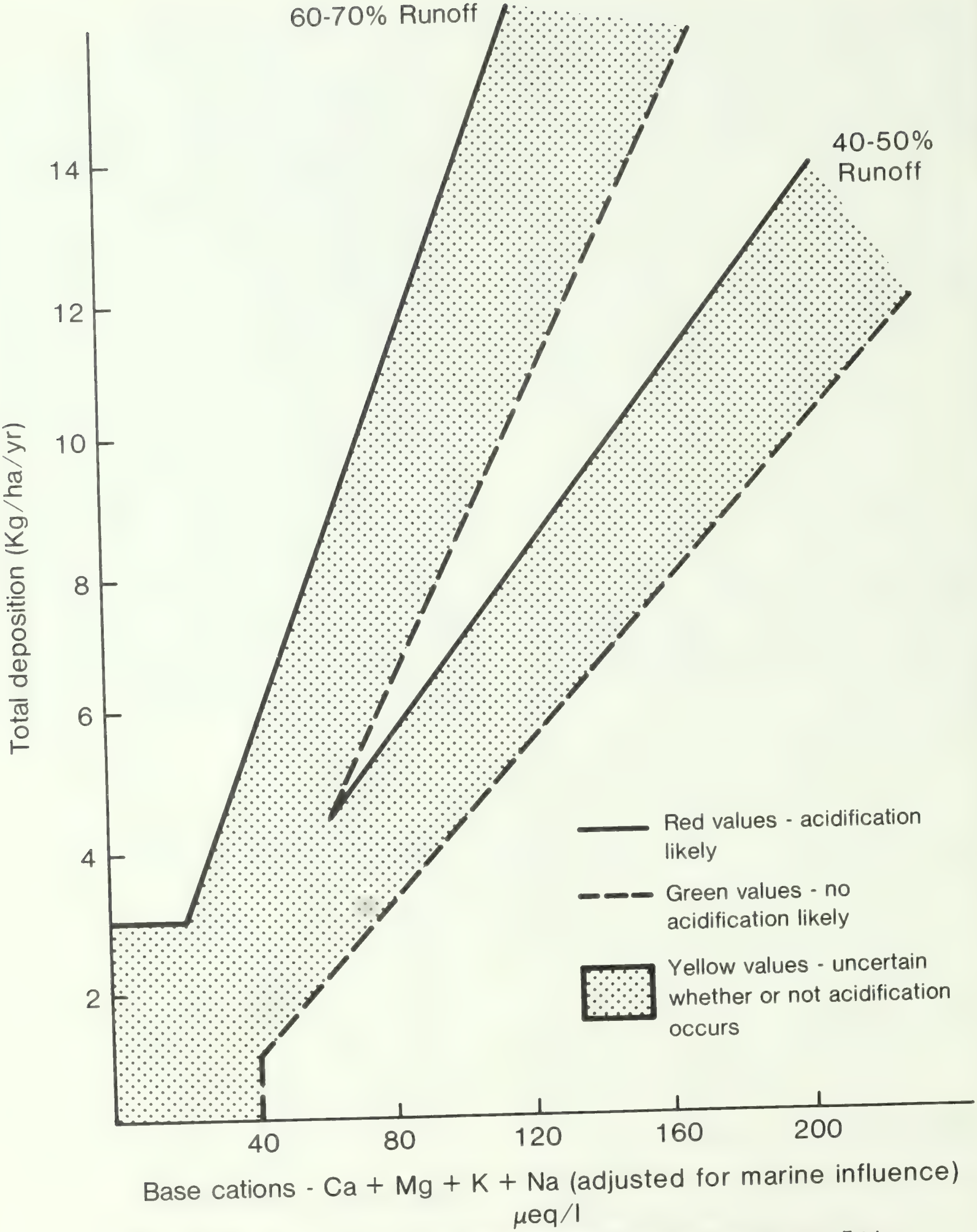

Figure 1.--Green and Red Line values for effects of deposition on freshwater systems. Total deposition is total sulfur deposition except for selected locations as noted in the text where 25% of total Nitrogen deposition should be included.

Part of the water that falls on a watershed as precipitation is lost as water vapor through evaporation or through transpiration by plants. Depending on geologic conditions, some may seep deep below surface and be lost from the immediate watershed as ground water. The rest leaves as surface runoff. High mountain areas with cool temperatures, large amounts of rain and snow, steep slopes, and thin soils have high runoff percentages. Warm temperatures, deep soils, level topography, and vigorous plant growth all favor evapotranspiration and reduce runoff.

Participants considered that, with a few complex exceptions, effects of N deposition on aquatic resources are not likely to be significant because the N is taken up by the watershed terrestrial and aquatic biota and does not contribute to acidification. Exceptions are very sensitive lakes and watersheds, primarily at high-elevation sites in the western United States, with base cation concentrations below 50 µeq/l. Such systems can be acidified by addition of N (Grennfelt and Hultberg 1986). For such circumstances, we recommend adding 25% of the total N deposition to the S deposition for use in the aquatic graph. Thus, if the total deposition projected for a western Class I area containing low base saturation waters is 2 kg S/ha-yr and 4 kg N/ha-yr, the value of $2 + .25 \times 4 = 3$ should be used in determining the Green and Red Line loadings on the Graph.

Below a total deposition of 3 kg S/ha-yr, there are no field data to develop the Green and Red lines. Particularly in Class I areas in the western United States, deposition levels are low and surface waters have low ionic concentrations (10-40 µeq/l). No evidence of chronic acidification has been reported. However, snow melt has the potential to seasonally acidify these surface waters. Another potential effect of episodic snowmelt loading in lakes in the west is eutrophication, a nutrient fertilization effect leading to increased organic productivity. This effect would also require additional study. Thus, these systems fall in the Yellow zone.

Implementing the Screening Technique

Information Needs

Listed below are six types of data helpful to managers for using the Green/Yellow/Red screening technique. These data can be obtained from published sources, or local scientists who may have access to additional sources of information. It is also prudent for managers to formulate recommendations for additional research or assessment efforts which should be undertaken by the permittee, Forest Service, state, or by other organizations before or as a condition to the permit.

Managers are encouraged to develop working relationships with local university, state, federal, and industrial research personnel to assist in identifying already existing sources of information or recommendations for further research. This workshop report should be useful in initiating such communication.

Data needed to responsibly evaluate a PSD permit include:

1. Deposition and air concentrations to estimate current loadings.--Current loading and exposure conditions at wilderness sites must be estimated to assess the impact of new deposition increments. Measurements should take into account expected higher fluxes at higher elevations. Some protocols for these measurements have been established (Fox et al. 1987).

Ozone. Determine maximum hourly average values and growing season average concentrations.

Sulfur. Determine total deposition by wet, dry, and cloudwater processes. For some forest systems it has been shown that measurements of throughfall plus stemflow fluxes provide a simple but accurate estimate of total deposition of the major S components.

Nitrogen. Determine total deposition from precipitation, cloudwater, and air chemistry measurements (including HNO_3 vapor and ammonium ion) and appropriate dry deposition models. Characterization of meteorologic and climatologic parameters should also be considered. These can be used to determine potential climatologic stresses and to evaluate dry deposition and cloudwater deposition.

2. Expected deposition and air concentrations due to proposed source.--Predicted loading and exposure at each site must be estimated to assess the change in current loading or air concentrations for comparison with Red and Green Line values. Estimates must account for elevational effects and for important nearby sources that contribute to background loading and concentration. The expected worst case ambient loading or concentration should be predicted. Modeling is generally conducted by the proponent and/or the regulatory agency. Managers should be aware that ozone is a secondary pollutant (generated in the atmosphere) and must be predicted with a model incorporating photo-chemical reactions. Sulfur modeling should include any increased loading due to all important sulfur species (SO_2, particle sulfate, cloudwater sulfate). Nitrogen modeling should consider all species of N available for plant uptake (HNO_3 vapor, nitrate and ammonium ions in rain and cloudwater, NH_3).

3. Inventory of biological resources associated with the identified AQRV's of the Class I area.--A description of the vegetation communities (type, cover) is needed to assess the relative response of the ecosystem(s) to pollutants. Include in a general assessment the identification of unique communities (such as small bog in an otherwise forested system), and the percentage cover of major ecosystem types.

Periodic remeasurement of stand composition and integrity. Linkage to developing long-term monitoring programs (EPA, FS) will assist in an evaluation of change. A species list including relative frequencies of occurrence is needed. An estimate of the biomass increment for assessment of nitrogen demand and use (for instance Douglas-fir require more than alpine plants) must be made. Percent cover by major vegetation type is useful for this purpose.

A full inventory of aquatic resources, including water column and benthic sampling to determine phytoplankton, zooplankton, and macroinvertebrates as well as associated water chemistry is needed. A quantitative sampling procedure for macroinvertebrates and flowing waters should be followed. Fish abundance, condition, age class, and other aspects of community composition should be measured (Fox et al. 1987).

4. Species response/biological effects data.--Following the vegetation survey, the response of key species to pollution loading must be evaluated. The FLM should coordinate these needs with FS Research and other research activities in the area of air pollution, plant response, acid deposition, and aquatic resources. One outcome of this might be the development of bioindicators and key sensitive organisms in Class I areas.

5. Lake, stream, and soil survey/geological assessment.--Data needs for lake and stream water chemistry are identified above. Information is necessary to understand the relative ability of soil and bedrock to buffer pollutant inputs for all subsystems within the wilderness.

Lake and stream water. Care should be exercised to ensure that appropriate guidelines are followed (see Fox et al. 1987).

Soil survey. Identify major soil series, followed by more detailed chemical characterizations of the important series. (See for example the description and protocols in the recent EPA Soil Survey; Fox et al. 1987.)

Geological assessment. Parent material can be assigned to one of several weathering as described in the Swedish critical load document (Nilsson 1986). Ecosystem sensitivity to S inputs can then be related to the percentages of the various classes within the wilderness.

6. Snowpack chemistry and hydrologic characteristics of the area.--Snowpacks in high-elevation wilderness have large surface area to capture S and N compounds. Thus pollution may accumulate in the snowpack. Careful measurement of snowpack chemistry (Fox et al. 1987) can provide good deposition loading information. Snowmelt causes a significant pulse of water which initially can release concentrated chemicals to the ecosystem. Since pollutants are not soluble in ice, they reside on the surface of the ice. As the snowpack warms, these chemicals are removed by the initial meltwater. This may result in a chemical pulse more concentrated in the initial runoff than in the snowpack itself. Managers should assess the potential and the likely effects of this process of pollutant storage and delivery.

Monitoring Considerations

A major consideration for all ecosystems is the current condition of the atmospheric environment. This requires measurement of meteorology and air quality in sites representative of the wilderness.

Meteorology

Meteorological instrumentation can be operated with battery power using microprocessors to record and process the data. The details of these systems are available in Fox et al. (1987).

Ambient Air Concentration

Air quality measurement is more problematical. Ozone measurement requires a major investment in an air-conditioned instrument shelter. The shelter and the ozone monitor require line power, frequent calibration, and standardization. Such instrumentation cannot be put in a wilderness. Rather, the site selected for monitoring ozone must be carefully selected to be representative in exposure, elevation, and ground cover (canopy, etc.) of the wilderness being monitored (Fox et al. 1987).

Ambient air concentrations of SO_2, NO_x, and NH_4 can be measured using filter packs. These filter packs also collect aerosol SO_4 and NO_3. These instruments also require power, although they need not be sheltered. Again, siting must be representative of the ecosystems being monitored. These techniques are described in Fox et al. (1987).

Deposition

A major concern in assessing impacts is the measurement of deposition. Dry deposition cannot easily be measured except with research quality instruments. However, it can be approximated by measurements of surrogates, for example snowpack in alpine areas. The snowpack can be monitored by

carefully digging a snowpit and collecting snow samples along its depth (Fox et al. 1987). In a forest, throughfall and streamflow together have proven a useful measure of dry deposition of some chemical elements.

Wet deposition should be measured using NADP-type collectors and protocols for consistency and comparison within the large national network. Other data required should be collected using the guidelines for wilderness measurements (Fox et al. 1987).

Cloud and fog water interception in certain locations can add considerably to the total deposition. They should be considered in mountain locations where such events occur.

General Considerations for Data Collection

The land manager should be aware of the degree of uncertainty in the numbers obtained, including those used to establish Red and Green Line values. The FLM should accept that some uncertainty is unavoidable and does not negate use in decision making. The following points are relevant.

1. The variance of certain measurements can be quite high, increasing the uncertainty in estimates, and decreasing confidence in prediction.
2. The level of resolution can increase uncertainty. Finer temporal resolution of data (such as hourly ozone averages) may be quite variable and difficult to interpret, but when averaged over a longer period of time (weekly), values are more stable and, hence, certain.
3. Temporal patterns in water and soil chemistry may or may not be greater than the magnitude of differences among soil types in the same watershed. The focus of the monitoring is on the most sensitive component of the ecosystem, rather than any average or representative condition.
4. Most wildernesses are comprised of several ecosystems (such as alpine at high elevation; Douglas-fir at lower elevation). The manager needs to evaluate the sensitivity and the importance of identified AQRV's in each ecosystem.
5. There may be mismatches between data sets. For example, air quality data may be provided for a region or large parcel of land (especially if derived from a model); however, the soil chemistry or vegetation type may be specific to a location. Also, microclimatic effects might alter an air-quality and/or deposition effect locally, reducing the representativeness of a measurement.

Quality Assurance and Quality Control

The need for quality assurance and quality control is implicit in the need for data upon which decisions can be upheld in an appeal. The following items reflect this need:

1. Utilize standardized quality assurance/quality control guidelines where available; in particular, EPA procedures and the QA Methods Manuals of the Forest Response Program (Blair 1986).
2. Implement standard protocols across regions. For soils, coordination with the Soil Conservation Service is recommended.
3. For chemical analyses, evaluate laboratory capability and performance prior to selecting a laboratory. Evaluation is especially relevant for many state and university laboratories where procedures may be appropriate for agricultural but not forest soils, and for lake and stream water but not necessarily dilute surface waters and precipitation. Water chemistry is particularly expensive and demanding on laboratory resources. Laboratory procedures should be carefully evaluated and monitored both prior to receiving samples and during sample analysis.

SPECIFIC FACTORS AND CONSIDERATIONS IN DEVELOPING THE MODEL

Terrestrial Systems

Effects of direct air pollution on terrestrial resources have been the subject of considerable research over the past 50 years. Many plant species have been tested for direct phytotoxicity due to the so-called criteria pollutants (O_3, SO_2, NO_x) as well as other reactive hydrocarbons. Concentrations necessary to cause a noticeable impact are generally well above the current loadings in many Class I areas, although ozone routinely occurs at phytotoxic levels in California and the eastern United States. The major problems associated with ozone toxicity are: (1) plants respond almost immediately to low concentrations of ozone, but their response is not likely to be significant until concentrations are somewhat higher than the response level (Reich 1987), and (2) generally only economically important plants have been studied. Other species may or may not respond in the same manner.

In the 1980's there has been a growing awareness of so called forest declines: large-scale reductions in the health and vigor of trees. Declines are likely associated with a host of interacting stress factors; direct causes are hard to pin-point. Research has been focused recently on determining the role of acidic deposition in forest decline. This program is rapidly

accumulating quantitative and qualitative information about the effects of addition of S, N, and associated pollutants on forest health. Considerable research is addressing the mechanisms of how S and N affects forests, including soil influences, foliar leaching, carbon allocation, winter injury, reproduction and regeneration, and insect and pathogen influences. Finally, direct dose-response relationships are being determined.

Workshop scientists considered the current state of this rapidly moving field in developing the numerical values in the Green and Red Line tables. In addressing ozone impacts they needed to address the critical question of what constitutes an ecosystem-level impact, given that most experiments have dealt with single species. An exception may be studies in California by Miller and his coworkers (Miller 1973).

When considering the levels of S and N deposition, the scientists focused on soil effects because soils were presumed to be a very sensitive ecosystem component, and clearly soil effects are an ecosystem-level impact. Dealing with N in this context was difficult, however, because most Class I area ecosystems are likely to be N limited. In this case any increment of N is likely to cause some effect. Scientists had to estimate the significance of anticipated effects at an ecosystem level in order to develop numerical values.

Rationale Used in Selecting Ozone Values

It has been well established that exposure of plant leaves to air containing ozone results in a number of quantifiable effects, including visible injury, reduced photosynthetic capacity, increased respiratory rate, briefer leaf retention time, and reduced growth (Barnes 1972, Hayes and Skelly 1977, Pye 1988). The magnitude of these effects depends on several factors, including the concentration of the pollutant, the duration of exposure, and other environmental factors (USEPA 1986). Sensitivity to ozone varies among and within species because of inherent differences in uptake rates (Reich 1987) and also because of other unknown genetic factors (Karnosky and Steiner 1981). Despite differences at the leaf level, responses of a wide variety of species types can be effectively characterized by taking into consideration exposure dynamics and uptake characteristics (Reich 1987).

The immediate effect of elevated ozone levels in wilderness areas would be decreased leaf longevity, reduced net carbon gain of foliage, reduced growth of individual plants, and foliar injury. Other adverse effects could include alteration of plant allocation of carbon; greater susceptibility to insects, pathogens, water stress, winter injury, or other stress agents; possible changes in species composition of plant communities; and possible loss of genetic resources of sensitive genotypes within a species.

The Green Line values for ozone for all wilderness terrestrial plant ecosystems are set at 75 ppb (peak 1-hour average) or 35 ppb (growing season average).[3] We follow regulatory procedures established by the Environmental Protection Agency, which define a peak as the second-highest one hour average concentration in a year (EPA 1986). Estimates of average ozone concentrations in clean air range from 15 to 30 ppb. However, estimates of background ozone concentration are very difficult because measurements do not exist, and models show complex nonlinear interactions where ozone production depends on NO_x concentration, nonmethane hydrocarbon (NMHC) concentration, and seasonality (Liu et al. 1987). NO_x background concentrations range from less than 1 ppbv (remote locations in the western United States) to about 7 ppbv (remote locations in the eastern United States) and about twice that in Europe (Fehnsenfeld et al. 1988). Modeling estimates (Liu et al. 1987) would then project background ozone concentrations of approximately 20 ppb in the western United States and 70 ppb in the eastern United States. Of course, NO_x and ozone concentrations in the vicinity of urban areas (such as Los Angeles, Phoenix, and Denver) are often higher than the eastern background.

The Green Line values were chosen to give reasonable certainty that no significant damage will occur to the ecosystem. Based on available information about plant response to ozone, we conclude that any increase in ozone levels above background (clean air) will have some adverse effect on individual leaves of at least some species. However, we believe that the integrity of the ecosystem can be maintained with the slight amount of stress on either sensitive individuals and/or sensitive species that might occur below Green Line levels.

The Red Line values for ozone are set at 110 ppb (peak 1-hour average) or 55 ppb (growing season average). Species from all plant types suffer reduced net photosynthesis and growth if exposed to 55 ppb for the daylight hours every day of the growing season. Although some of the data used in the development of this value are based on average concentration during daylight hours only (12 hours), the loading value seasonal averages use 24 hours per day. While it is an area of scientific controversy (Musselman et al. 1988) whether a 12-hour or a 24-hour based ozone season average is better correlated with effects, 12-hour data are not available from regulatory agencies. Thus, 24-hour data are recommended to calculate seasonal averages.

[3]*Growing season average may not be available in many locations, and determination of growing season will be specific to each species. Thus, it is likely that the peak values will be more useful than the growing season average values (USEPA 1986, Musselman et al. 1988).*

Ambient ozone levels in Class I areas should not exceed peak annual 1-hour average values of 110 ppb. Data from numerous ozone monitoring stations suggest that exceeding 110 ppb for the peak 1-hour period of the year would be accompanied by 15 to 50 (or more) hours of exposure to ozone levels greater than 80 ppb. Adverse effects are greater at higher ozone concentrations.

Ozone effects are cumulative for each individual plant, but the chemical itself is ephemeral and does not accumulate in the plant or ecosystem. Also, ozone does not enter the soil in sufficient quantities to be of any significance. Finally, we conclude that some individuals and species will be damaged in all wilderness ecosystems at ozone levels between the Red and Green Line values. In such Yellow Zones, predicted damage must be evaluated on a case by case basis. The PSD recommendation may depend on the relative value of the plant community as an AQRV within that particular wilderness area.

Rationale Used in Selecting Sulfur Values

Two criteria or effects have been considered to set the Green and Red Line levels of deposition for sulfur: (1) removal of base cation from soils in association with the SO_4^{2-} anion, a "capacity" effect, and (2) the "intensity" effects resulting from the changes in soil solution composition. This distinction becomes important in areas affected by marine air masses where natural SO_4^{2-} levels may be well above our proposed Green Line values. An approximate correction can be made by subtracting the marine component based on the SO_4^{2-}/Cl^- ratio in seawater. Marine sulfate is generally not considered deleterious because it is normally accompanied by base cations, particularly Na and to some extent Mg, and thus does not contribute to acidification of the system. There may be episodic exceptions to this.

For our basic capacity comparisons, we have assumed a soil depth of 30 cm with a bulk density of 1.1 kg/liter. At a loading of 3 kg S/ha, it would require approximately 175 years to achieve a reduction of 1 meq of base cations per 100 g soil. This reduction would be at least partially offset by weathering of primary minerals. Somewhat higher deposition levels would be acceptable in areas where soils are deep or are well supplied with bases, and these considerations are reflected in the proposed values for some of the particular ecosystems.

Given these assumptions, the maximum allowable (Red Line) values of 20 kg/ha of S could achieve the reduction of 1 meq base cation within about 26 years. This base cation reduction would generally be unacceptable unless the system contains free $CaCO_3$. However, with the possible exception of the Superstition Wilderness, all of the specific ecosystems considered here contain considerable areas of non-calcareous soils.

For our evaluation of intensity effects, we have assumed 1 m precipitation in excess of evapotranspiration. The Green Line value of 3 kg/ha would increase solution concentrations by about 19 µeq/l, which is near the natural background for surface waters in areas that do not contain significant amounts of readily oxidizable sulfur-bearing minerals. Furthermore, this concentration would be unlikely to result in significant mobilization of soluble inorganic forms of aluminum. The corresponding increase for the maximum value of 20 kg/ha would increase solution concentrations by about 125 µeq/l. This concentration is in the range where Al mobilization might occur in acid soils, and with the possible exception of the Sonoran systems, would probably not be acceptable.

Rationale Used in Selecting Nitrogen Values

The basic features of N cycling in forest ecosystems are fairly well understood, and can provide a broad conceptual outline for arriving at deposition loadings to wilderness areas. The following is a brief summary of some of the important features of N cycles relevant to loading considerations.

Nitrogen is the only major plant nutrient that does not accumulate to any significant extent in inorganic forms in the soil. Although ammonium is strongly adsorbed to soil cation exchange sites, ammonium almost never significantly accumulates because of biological uptake by plants, grazers, decomposers, and nitrifying bacteria. Thus, forest ecosystems can accumulate atmospherically deposited N only by biological mechanisms; specifically through incorporation into plants, plant feeders (herbivores), and decomposers such as soil microorganisms and invertebrates. Because N is the nutrient most commonly limiting growth of forests in North America, forested ecosystems usually show a net accumulation of atmospherically deposited N.

Any increase in N deposition as nitrate or ammonium ion to N-limited wilderness areas will most probably result in some increase in growth, and may actually improve the health of the ecosystem. Species adapted to low N conditions might be replaced as a result of fertilization. It is also possible that chronic N enrichment may eventually predispose plants to outbreaks of plant-feeding insects and fungal pathogens because of changes in the plants' carbon allocation to growth and defensive processes.

N deposited in excess of biological need almost invariably leads to nitrification, microbially mediated nitrate and nitrite formation in the soil, and increased leaching of nitrate and associated cations. The nitrate so produced may lead to surface- or groundwater

degradation unless it encounters anaerobic conditions. Under these conditions, it may be microbially reduced to N_2O gas (denitrification), thus decreasing the potentially deleterious effects of excessive N deposition on water quality. These processes may still leave the potential increases in soil acidification to be considered.

The Green Line values (3-10 kg/ha-yr) for nitrogen, across all the ecosystems considered, were selected to give reasonable certainty that no significant change in the forest ecosystem will occur below this amount of nitrogen deposition.

The Red Line values (10-15 kg/ha-yr) for nitrogen, across all the ecosystems considered, were selected to give reasonable certainty that these amounts of nitrogen deposition will result in significant cnanges in the accumulation of nitrogen and in the species composition or other important features of the ecosystem.

While the fundamental elements of forest N cycles are reasonably well understood, quantitative data on N cycling in wilderness areas is quite scarce at best, and in many areas completely lacking. Therefore, the Red and Green Line loadings for N deposition in wilderness areas are judgments based on a very limited database. We strongly urge that relevant N cycling parameters be measured in those wilderness areas for which there is a potential concern about increased N deposition. It is also important to note that atmospheric deposition at the chosen target loadings may well have some effect upon wilderness areas in terms of stimulating growth; thus, there is no assertion that these levels will protect the wilderness areas from all effects. In our judgment, however, the Green Line levels are sufficiently low that perceptible deleterious effects upon plant health, changes in species composition, or degradation of water quality are unlikely.

Aquatic Systems

Aquatic resources are important Air Quality Related Values in most Class I areas. Determining how best to prevent significant deterioration by atmospheric pollutants, however, is not as straightforward as establishing their importance.

This section provides general guidelines for all surface waters relative to the amount of sulfur and nitrogen that can be deposited on an annual basis.

Green Line values indicate levels *below* which it is highly *unlikely* that the most sensitive aquatic resources will be significantly affected, while Red Line values indicate levels *above* which it is highly *likely* that the most sensitive aquatic resources will be significantly affected.

The guidelines use the concentrations of base cations: calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), as a measure of sensitivity. The sulfur and nitrogen loadings above which adverse change is likely and below which change is unlikely are based on the most sensitive waters.

Concept of Surface Water Sensitivity

Lakes and streams differ in their inherent sensitivity to inputs of acidifying compounds from the atmosphere. A number of factors affect lake sensitivity; bedrock geology, soil and vegetation type, hydrologic characteristics, lake chemistry and biology, and precipitation volume are among the important factors. Maps of bedrock geology are often used to indicate areas with sensitive lakes and streams. Seepage lakes, lakes which have no visible outlet, are likely to be dominated by precipitation, while drainage lakes are likely to be influenced by watershed base cation supply. Seepage lakes, all other things being equal, will be more sensitive to acidification. The lake or stream chemistry itself provides a convenient measure of sensitivity. The lake water integrates many watershed factors that may be difficult to measure or estimate in the field.

Any of several water chemistry parameters may be used to estimate sensitivity. In pristine areas receiving little or no acid deposition, acid neutralizing capacity (ANC) provides a useful measure--the lower the ANC, the more sensitive is the water body. In areas receiving acid deposition, however, ANC may have decreased. Since ANC changes with acid deposition, it cannot be used directly to assess sensitivity. Acid neutralizing capacity can be defined as the sum of the base cations minus the sum of the strong acid anions (SO_4^-, NO_3^-, Cl^-) in a water sample if concentrations of organic acids and aluminum are insignificant. Because of the principle of electroneutrality, changes in base cations and/or acid anion concentrations must affect the ANC of the sample.

Calcium and magnesium concentrations have been used widely as a measure of inherent sensitivity. Henriksen's (l979) empirical nomograph for lake acidification uses Ca+Mg concentrations as a measure of sensitivity and SO_4 concentration (or alternatively pH of precipitation) as a measure of acid deposition to determine whether a given lake will be acidic (pH<4.7), transitional (4.7-5.3), or bicarbonate dominated (pH>5.3). This empirical approach developed on the basis of several hundred Norwegian lakes has been shown to be of general applicability to lakes in many regions of Europe and North America (Wright and Henriksen 1983, Henriksen and Brakke 1988, Wright 1988, Reuss et al. 1986).

While Ca and Mg are the major cations usually

associated with alkalinity, the weathering of minerals containing K and Na can also contribute significantly to ANC. Given the geological diversity of the Class I areas, we used the sum of the four major base cations (adjusted to subtract any marine influences) as the principal measure of inherent sensitivity.

The relationships between lake ANC, anions, base cations (Ca+Mg+K+Na), pH, and conductivity can be derived either empirically or from basic water chemistry theory. The figures used for our screening technique were constructed showing the relationships between non-marine base cations and total S or S+N deposition for sensitive lakes. Measured lake chemistry data from the 1984 Eastern Lake Survey (Linthurst et al. 1986) and the 1985 Western Lake Survey (Landers et al. 1987) were used. Total deposition for S and N were estimated for eastern lakes from analysis of wet deposition data done by Husar (1986) with 30 percent added to account for dry deposition. For the western lakes we averaged data from nearby high-elevation National Atmospheric Deposition Program (NADP) sites (NADP 1988) with data from high-elevation snow chemistry studies (Brown and Skau 1975, Melack et al. 1982, Laird et al. 1986, Loranger 1986, Loranger and Brakke 1988, Reddy and Classen 1985, Vertucci in press). No additional correction was made for dry deposition because not enough information is available to estimate the potential contribution (Young et al. 1988).

Acidification Response Levels

The effects of O_3, N, and S can be assessed directly for aquatic ecosystems. Ozone has no known direct effects on aquatic systems, and therefore does not warrant further consideration. For aquatic systems, pollutant loadings by N and S exert their influence on biotic communities primarily by changing pH conditions rather than by a direct influence due to the chemical species of N or S. Our focus, therefore, is on defining threshold levels for N and S loading based on their influence on pH. Again in very dilute, high-elevation N-limited lakes, the addition of N can initiate eutrophication.

Changes in lake or stream pH due to atmospheric inputs of N and S can have a variety of direct and indirect effects on aquatic communities and ecosystem processes. Increased hydrogen ion concentrations can have a direct, toxic effect on organisms. Such direct effects on one or a group of organisms may exert, subsequently, an indirect influence on the occurrence of other organisms, primarily through food web interactions. Changing pH may also influence the solubility of nutrients or toxic compounds and elements (such as aluminum) which in turn may affect the occurrence of organisms either directly or indirectly. It is important to note that small-scale changes in chemical conditions are likely to affect physiological processes or a particular life stage of an organism prior to the disappearance of a taxon.

Information on the effects of a particular decrease in pH on a lake or stream can be derived from four types of sources (EPRI 1986): (1) laboratory bioassays, (2) synoptic surveys of the distribution of organisms across systems with a range of pH values (Eilers et al. 1984, Confer et al. 1983, Haines 1981), (3) manipulations of pH in mesocosms, and (4) whole-system experimental manipulations of pH (Schindler et al. 1985, Brezonik et al. 1986, Hall et al. 1980, Hall and Likens 1981). Each of these sources can provide useful information on the effects of changing pH conditions. However, whole-system experiments provide the best detailed information on the response of aquatic systems to acid stress because they involve a direct, controlled manipulation of pH conditions, and they are conducted at a scale that encompasses a full range of population and ecosystem processes (Schindler 1988, Hall and Likens 1984). Specifically, results from these studies indicate effects that *could not* have been discovered with other approaches.

In general, considering information drawn from all of the sources listed above, it is possible to conclude that pH changes of less than 0.5 units are capable of producing considerable change in the biotic communities of either lakes or streams. In many cases, fish populations would be expected to respond to a 0.5 unit pH change. Shifts of 1 pH unit can lead to major changes in the occurrence of other organisms, particularly sensitive ones such as mollusks. Workshop participants suggested a 0.5 pH unit change as a Red Line projection and a 0.1-0.2 unit projected change for the Green Line, in sensitive systems with pH of order 6 or very low ANC.

Because many wilderness areas contain a diversity of lakes and streams, it is important to target a subset of lakes and streams as primary AQRV's. Generally, lakes and streams with low base cation concentrations (BCC) or acid neutralizing capacity (ANC) are most likely to be affected by the lowest level of pollutant input. The federal land manager should therefore target the lowest BCC and ANC systems within a wilderness area for evaluation. An inventory of the BCC and ANC of aquatic resources in an area would provide extremely valuable and cost-effective baseline information. Among the low BCC lakes and streams, those with pH values of around 6.0 may be the most likely to change with an increased S or N loading, and should be given the most detailed attention. Typical symptoms of acidification for lakes and streams include the development of extensive mats of filamentous green algae, increased water clarity, and/or changes in

the proportional occurrence of macroinvertebrate species (Schindler et al. 1985, Hall et al. 1985, 1987). It is also important to note, however, that a shift in the pH of a lake or stream with a current value of 7.0 is also likely to cause changes in the biota.

In some wilderness areas, lakes or streams may already have pH<6.0. In many cases these could be naturally acid rather than anthropogenically altered systems. Natural acidification is often the case where sphagnum bogs occur and runoff waters are yellow-brown stained. These waters can have high organic carbon concentrations, and therefore the natural contributions to acidity may be high. Although such naturally acid systems may contain assemblages of species that are adapted to low pH conditions, they may still be sensitive to the effects of increased N and S loading. These colored water systems require more detailed consideration.

Although the graphs presented are based on S deposition, N may, in some circumstances, also affect lake acidification. To account for the acidifying effect of N deposition, we again used an empirical approach. Generally, most N inputs are retained in the terrestrial ecosystem. The fraction that leaks out to surface water depends on a variety of site factors such as vegetation type, stage of ecosystem development, hydrology, and history of acid deposition. Large leaks of N often result from vegetation disturbance such as clearcutting, fire, and windthrow (Likens et al. 1970, Bormann and Likens 1979).

Henriksen and Brakke (1988) have shown from empirical data for surface waters in Norway that the percent of incoming N retained by the terrestrial system is generally 75-100%. Many of these lakes and streams are comparable chemically and biologically to mountainous areas in the United States. Some acidified areas have shown an increase in NO_3^-, while unacidified areas have very low concentrations of NO_3^- in runoff (Henriksen and Brakke 1988).

While there will be unusual situations where N can be released from ecosystems, a general exception is extremely sensitive high mountain lake watersheds. For such high elevation systems (BCC<50 µeq/l), adding 25% N deposition to the S deposition is merely a guideline because the uptake will vary from site to site, and also over time at a given site. Our approach here is based on current situations measured at lakes and streams of varied sensitivity and receiving varied amounts of acid deposition both as N and S.

S and N Loadings

Current S and N loadings are necessary to locate the lake(s)/stream(s) on the nomograph (fig. 1). The S loading should be total S (wet SO_4 + dry particulate SO_4 + SO_2 gas) and can probably be best estimated from the NADP wet deposition fields + measured SO_2 levels, combined with best estimates of deposition velocity. N loading (NO_3^- + NH_4^+) can be calculated in an analogous manner for cases (BCC<50 µeq/l) where N is to be considered.

Illustration of Graph Use

For example, assume that lake water quality has been identified as an AQRV, and that pH was chosen as a measurement to be monitored. Lake pH, identified as an indicator of the health of the aquatic ecosystem, needs to be maintained above 5.8. This is equivalent to maintaining an ANC over 10 µeq/l in water. Data have been collected that identify a particular lake whose base cation concentration is 80 µeq/l. The screening concept in the Aquatic Graph (fig. 1) is to be applied to this lake.

Since the lake in this example has a measured non-marine base cation sum of 80 µeq/l, the results are 3 kg S/ha/yr and 5.5 kg S/ha/yr for Green and Red Line deposition loading, respectively, if runoff is between 40-50% of precipitation. If runoff is 60-70% of precipitation, the Green Line deposition is 6 kg S/ha/yr and Red Line is 11 kg S/ha/yr. That is, if the low runoff lake would receive a total of <3 kg S/ha including deposits from the new source, the pH of the lake would not likely drop below 5.8. The AQRV would not be adversely impacted, and the recommendation to the state regulatory agency would be for permit approval. If the low runoff lake would receive a total of ≥5.5 kg S/ha/yr, including deposits from the new source, the pH of the lake would certainly drop below 5.8 and probably below 5.0. The AQRV would be adversely impacted, and the recommendation to the state regulatory agency would be for permit denial or permit modification, to reduce deposition from the new source to levels that would not adversely affect the lake.

Total deposition, including that from the proposed new source, between 3 and 5.5 kg S/ha-yr would have uncertain effects on the lake pH. The assessment would then require additional site-specific information indicating physical, chemical, and/or biological response to sulfur input.

Information Needs

To use the Aquatic Graph (fig. 1), the following information is needed:

- Distribution of cations, anions, ANC, and pH in wilderness lakes and streams, collected after spring runoff has receded.

- o Estimates of annual runoff for watersheds containing low base cation (sensitive) systems.
- o Estimates of background annual average (wet plus dry) sulfur and nitrogen deposition.
- o Estimated total S and N deposition based on modeling of the proposed new source emissions.

Cautions

The aquatic Green/Red model developed at this workshop is based on an empirical relationship involving a large number of lakes and streams. These aquatic systems differ in watershed biogeochemistry and hydrology, and in their specific response to incremental additions of sulfur or nitrogen loading. The loadings themselves are based, in most cases, on estimated atmospheric values developed from models that use regional assumptions and "rules of thumb." Empirical models are best used as a screening technique to estimate the probability of a water body or group of water bodies responding to a given sulfur or nitrogen deposition rate in cases where minimal data are available. The terrestrial Green/Red Line model is equally approximate.

Empirical models are not able to predict exact results in any specific ecosystem. Because all of the assumptions in this report are conservative, a loading value below the Green Line has a low probability of causing negative effects on AQRV. However, there remain some sources of error that would cause an underestimate of the potential for wilderness acidification:

- o Failure to include the most sensitive lakes or streams.
- o Overestimation of average annual runoff.
- o Underestimation of background S or N deposition.
- o Underestimation of nitrogen assimilation and storage by watershed vegetation and litter.
- o Episodic acidification due to acidic snowmelt or storm events (primarily in streams).
- o Higher than normal initial concentrations of SO_4 in lakes from natural sources other than marine sources.
- o Failure to correct lake cation values for marine influence or for other geological sources of Cl and associated anions.

The nitrogen loading data also do not consider possible effects of increased nitrogen on eutrophication (algal growth) and consequent low dissolved oxygen content in lakes.

If a loading appears above the Green Line, the graph indicates that the lake or stream may experience a pH below 5.8. The following factors lead to an overestimation of the effects of the predicted future loadings.

- o Overestimation of background sulfur loadings due to:
  - --a large component of alkaline sulfate dust.
  - --overestimation of background dry deposition rates.
- o Overestimation of background nitrogen loading due to:
  - --overestimation of dry deposition rates.
  - --underestimation of nitrogen assimilation by watershed vegetation.
- o Delayed response to loadings because of:
  - --high sulfate adsorption capacity of watershed soils.
  - --higher than average background weathering rates.

If a loading falls above the Green Line criterion value, the manager should request data from a proponent as part of the PSD permit to determine if one or more of the above cases may apply. Determinations would involve deposition chemistry measurements (including dry deposition), watershed element budgets, analyses of watershed soils, and watershed simulation models. Such studies should be suggested or approved following consultation with scientists.

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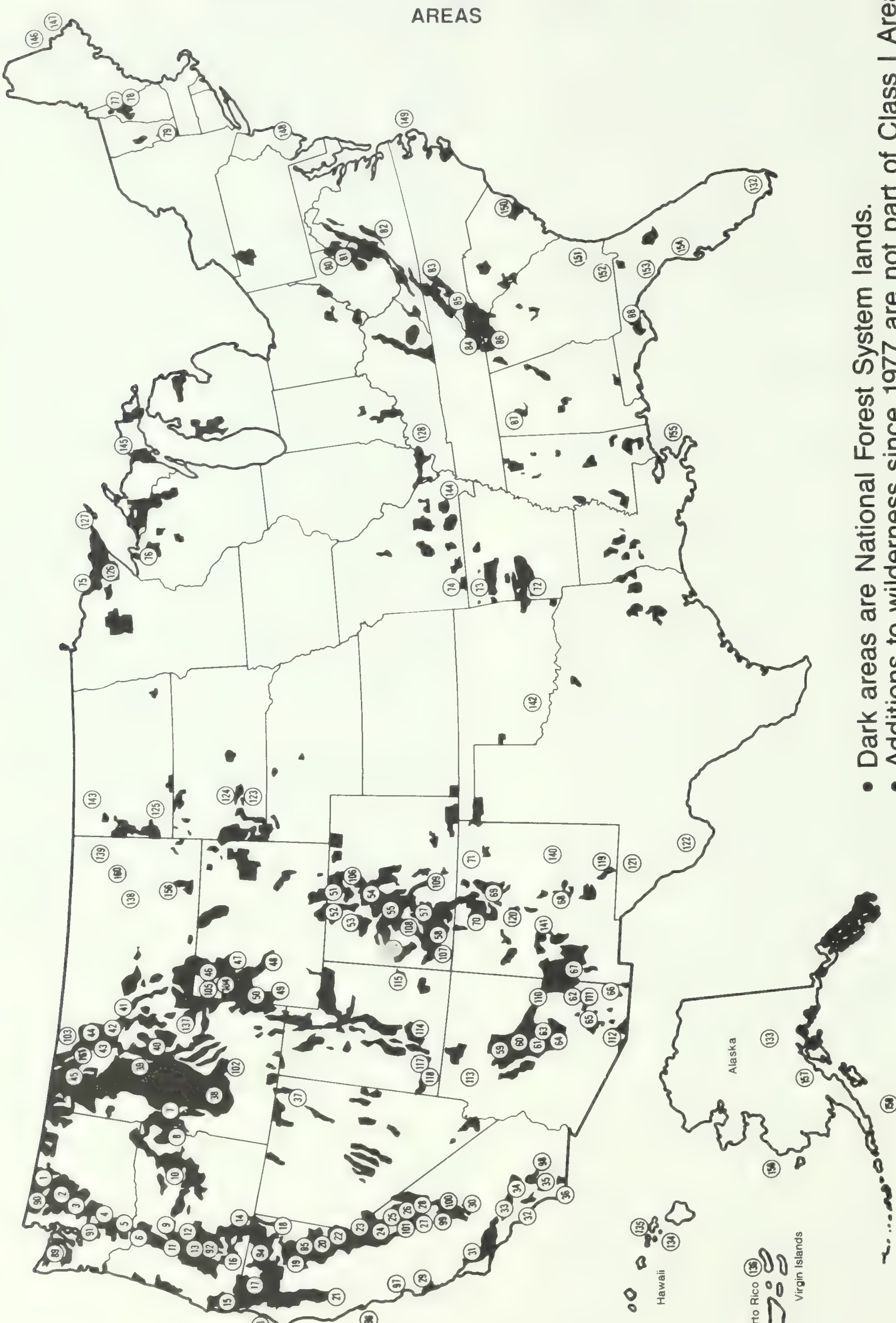
APPENDIX A. MAP OF FOREST SERVICE CLASS I AREAS



- Dark areas are National Forest System lands.
- Additions to wilderness since 1977 are not part of Class I Areas.

Figure A-1.--USDA Forest Service wildernesses and acreages designated by Congress August 7, 1977 as Class I areas.

WASHINGTON

1	Pasayten	505,524
2	Glacier Peak	464,258
3	Alpine Lakes	303,508
4	Goat Rocks	82,680
5	Mt. Adams	32,356

OREGON

6	Mt. Hood	14,160
7	Hells Canyon	See ID
8	Eagle Cap	293,476
9	Mt. Jefferson	100,208
10	Strawberry Mtn.	33,003
11	Mt. Washington	46,116
12	Three Sisters	199,902
13	Diamond Peak	36,637
14	Gearhart Mtn.	18,709
15	Kalmiopsis	76,900
16	Mountain Lakes	23,071

CALIFORNIA

17	Marble Mtn.	213,743
18	South Warner	68,507
19	Thousand Lakes	15,695
20	Caribou	19,080
21	Yolla-Bolly-Middle Eel	109,091
22	Desolation	63,469
23	Mokelumne	50,400
24	Emigrant	104,311
25	Hoover	47,916
26	Minarets (Now Ansel Adams)	109,484
27	Kaiser	22,500
28	John Muir	484,673
29	Ventana	95,152
30	Dome Land	62,206
31	San Rafael	142,722
32	Cucamonga	9,022
33	San Gabriel	36,137
34	San Gorgonio	34,644
35	San Jacinto	20,564
36	Agua Tibia	15,934

NEVADA

37	Jarbridge	64,667

IDAHO

7	Hells Canyon	193,840
38	Sawtooth	216,383
39	Selway-Bitterroot	1,240,618

MONTANA

39	Selway-Bitterroot	See ID
40	Anaconda-Pintler	157,803
41	Gates-of-the Mtn.	28,562
42	Scapegoat	239,295
43	Mission Mountains	73,877
44	Bob Marshall	950,000
45	Cabinet Mountains	94,272

WYOMING

46	North Absaroka	351,104
47	Washakie	686,584
48	Teton	557,311
49	Fitzpatrick	191,103
50	Bridger	392,160

COLORADO

51	Rawah	26,674
52	Mt. Zirkel	72,472
53	Flat Tops	235,230
54	Eagles Nest	133,910
55	Maroon Bells-Snowmass	71,060
56	West Elk	61,412
57	La Garita	48,486
58	Weminuche	400,907

ARIZONA

59	Sycamore Canyon	47,757
60	Pine Mtn.	20,061
61	Mazatzal	205,137
62	Mt. Baldy	6,975
63	Sierra Ancha	20,850
64	Superstition	124,117
65	Galiuro	52,717
66	Chiricahua	18,000

NEW MEXICO

67	Gila	433,690
68	White Mtn.	31,171
69	Pecos	167,416
70	San Pedro Parks	41,132
71	Wheeler Park	6,027

ARKANSAS

72	Caney Creek	14,344
73	Upper Buffalo	9,912

MISSOURI

74	Hercules-Glades	12,315

MINNESOTA

75	Boundary Waters Canoe Area	747,840

WISCONSIN

76	Rainbow Lake	6,388

NEW HAMPSHIRE

77	Great Gulf	5,552
78	Presidential Range-Dry River	20,000

VERMONT

79	Lye Brook	12,430

W. VIRGINIA

80	Dolly Sods	10,215
81	Otter Creek	20,000

VIRGINIA

82	James River Face	8,703

N. CAROLINA

83	Linville Gorge	7,575
84	Joyce Kilmer-Slickrock	14,033
85	Shining Rock	13,350

TENNESSEE

84	Joyce-Kilmer-Slickrock	See NC

GEORGIA

86	Cohutta	33,776

ALABAMA

87	Sipsey	12,646

FLORIDA

88	Bradwell Bay	23,432

APPENDIX B. BACKGROUND OF SAMPLE CLASS I AREAS

These descriptions were prepared jointly by scientists and managers at this workshop. The precision of these descriptions varies because the amount of information available to workshop participants was different. These Class I areas show the breadth of AQRV's considered and the diversity of approaches suggested by participants working together. Terrestrial values given each area may be the same because the different areas contain ecosystems with similar sensitivities, such as alpine areas. It is essential to consider the details of a specific Class I area being screened when applying information contained here.

Although visibility is an important AQRV in all these Class I areas, this workshop focused on the effects of air pollution on biotic systems and did not address physical impacts on visibility. In no way should the absence of visibility as an AQRV be construed as a judgment of its relative value compared to biological components.

Alpine Lakes and Glacier Peak Wildernesses - Washington

Brief Description

The Alpine Lakes and Glacier Peak Wildernesses are typical of the North Cascade mountains. The vegetation is fir, Douglas-fir, and hemlock, and precipitation is high. Soils are diverse in origin with modest fertility and moisture. This is a high mountain area with general elevation above 6,000 feet. Lakes and large perennial snow fields are common at the higher elevations. Streams peak during snowmelt runoff, but abundant year round stream flow persists.

Air Quality Related Values

Water flowing from the Cascade crest has significant value. The hydrologic system includes snowfields, glaciers, high mountain streams, small cirque lakes, cascading waterfalls, and larger streams and rivers in lower systems. The water and aquatic biota systems contribute greatly to these wildernesses. Maintaining these systems and their natural water clarity depends upon little chemical degradation or change.

These wildernesses include a wide variety of diverse plant communities and species typical of the northern Cascade range. Maintaining natural diversity is a critical component of general health and balance of the ecosystem. Any significant change in plant communities due to the effects of air pollution would not only change the quality of wilderness experience, but also ecosystem interrelationships which contribute to wilderness values.

Much of the wilderness experience in the Cascades is influenced by sights, sounds, feelings, experiences, and even the smells the visitor encounters. In areas close to metropolitan areas, one of the significant changes for the city resident is the smell of the great out-of-doors. Whether it is a whiff of pine forest, an aroma of rain forest, or briskness of the clean, crisp high mountain air rising up and over the Cascade range, natural smell is a value only truly appreciated when it's replaced with the odor of civilization.

Hoover and Dome Land Wildernesses - California

Brief Description

Hoover: This Wilderness lies along the eastern slope of the Sierra Nevada Range in Mono County, California. It is bounded on the west by Yosemite National Park, which lies on the western slope of this Range. The area is characterized by recently glaciated canyons, composed of granitic and metavolcanic rocks. The vegetation is scattered among the rocky flats and ledges of the Sierra granite batholith.

Most soils are derived from granitic rock, are weakly developed, and are low in productivity. They are typically shallow over granitic parent material on the sloping areas, and are deeper in the canyon bottoms. They are sandy textured and low base saturation. Water quality is good to excellent, with low sediment loads in the streams. The many lakes in the high country act as natural sinks in absorbing sediments from the canyon uplands.

Scattered stands of timber grow on approximately 11 percent of the wilderness. Timber types generally are mixed conifer, with Jeffery pine and white fir dominating the lower elevations and lodgepole pine and limber pine dominating the higher elevations. Subalpine meadows occur throughout the area; riparian areas exist along the stream courses, springs, and other water influence zones. The higher elevations are dominated by subalpine and alpine shrubs and herbaceous vegetation, while elevations below the forest zones are dominated by sagebrush, bitterbrush, and mountainmahogany.

Air quality within the wilderness is excellent. Among potential threats is the possibility for NO_X, SO_X, and ozone to drift up the Toulumne valley, flow over the crest, and influence the AQRV of the area and acidify precipitation.

Dome Land: The Dome Land Wilderness is located on the southeastern slopes of the Sierra Nevada Range at the southern end of the Kern Plateau. Granite domes and unique geologic formations are the dominant features. Climatic conditions range from montane to semi-arid to desert with elevations from 3,000 to 9,700 feet above sea level. The South Fork of the Kern River flows through the wilderness.

Dome Land geography has been primarily influenced by the South Fork Kern River drainage. The wilderness is rimmed by high elevation peaks in a horseshoe configuration. Pollution may be transported up the Kern River drainage from the Bakersfield area of the San Joaquin Valley.

The Dome Land is covered mainly by mixed conifer forest. The higher elevations support primarily lodgepole and Jeffrey pine, red and white fir, and small amounts of oak and various shrubs. Small stands of limber and foxtail pine are also found at the higher elevations. A unique association of limber and foxtail pine at the southern most ends of their ranges has resulted in the establishment of a research natural area. The lower elevations support mainly pinyon, digger pine, oak, and shrubs.

Wildlife in the Dome Land is abundant. The wilderness provides summer range for the Monache and Kern River deer herds. A comprehensive species list is lacking, but other wildlife observed include quail, squirrels, chickaree, chipmunk, marten, marmot, black bear, mountain lion, and bobcat. In the 1970's California condors were sighted on several occasions.

There is light to moderate fishing within the wilderness. The heaviest fishing area is located on the South Fork of the Kern River. The rainbow trout found in the wilderness are introduced.

The Dome Land contains six major tributary streams of the South Fork of the Kern River. The general character of the wilderness is dry during the normal season of use, so these streams are very important to visitors, livestock, and wildlife. Below the wilderness, water from the South Fork is used for agriculture, recreation, electrical power, and domestic supplies. All of the Kern tributaries in the wilderness drop to a low level or become dry in late summer. Water becomes quite warm in creeks still flowing.

Soils within the Dome Land are derived form weathered granite. Most of the soil consists of coarse, sandy materials that have weathered from the barren, exposed rock that dominates the wilderness. These soils are very young, and lack the development characteristic of older soils. They are very infertile due to coarseness, shallowness, and lack of capacity to store water. The soils are also susceptible to erosion.

Air Quality Related Values

Jeffery and ponderosa pines are prevalent above 5,000 feet. These sensitive tree species are subject to damage by ozone, and can be used as indicators of changes in plant communities. Needle retention and natural color are needed to maintain the aesthetics of these wildernesses. Limber, foxtail, and pinyon pine are also important vegetative species.

The buffering effect of meadows on water quality and quantity makes these areas very valuable for protecting the Class I areas' aquatic systems, especially the rainbow trout fisheries. Meadow condition and water quality should be maintained within current biological variability. Water quality needs to be maintained in the river and its tributaries.

The selected loadings for these wildernesses are lower than in some other wildernesses because of the presence of alpine ecosystems with limited ability to buffer additional S and N. The desire to maintain current ecosystem structure and function were primary considerations in the selection of threshold values.

The granitic domes characteristic in this wilderness should be protected.

San Gorgonio Wilderness - California

Brief Description

Geology of this wilderness is highly diverse and typical of southern California mountains. Climate is Mediterranean, and the soils are dry with base saturations about 50%. Water resources are scarce. Vegetation varies with elevation from chaparral through a pinyon-juniper and pine forest to alpine.

Air Quality Related Values

Ponderosa pine and Jeffery pine are dominant species known to be susceptible to air pollutants, especially O_3. Symptoms of ozone injury (needle chlorosis and premature needle senescence) can be readily identified. The ponderosa pine forests in southern California often have high concentrations of pollutants present. West of the San Gorgonio Wilderness, ozone concentrations are high from May through September, with moderate concentrations at other times. Nitrogen deposition is very high, and although poorly quantified, may be an important component of the ecosystem (Riggan et al. 1985).

Water quality is important as it relates to pH, ANC, and productivity. The pH and ANC values are related to changes in acidity, which affect chemical processes and ultimately biological processes. Productivity is a general term that refers to the amount of carbon fixed on an annual basis; more N-rich systems are generally more productive. Productivity should be maintained.

Meadows are critical areas to maintain in subalpine and alpine ecosystems.

Bob Marshall Wilderness - Montana

Brief Description

The Bob Marshall Wilderness is nearly one million acres in size, located in northwest Montana in the Rocky Mountain Province. The bedrock is mostly precambrian meta-sedimentary argillites, quartzites, and limestones. Glaciation influenced the shape of the land and the composition of the soil. Soils are cool, moist, with base saturation of 25 to 50% with a volcanic ash surface ranging from 4 to 8 inches. The terrain has been influenced by glaciation, which formed high alpine basins and broad u-shaped valleys.

Precipitation ranges from 16 inches in the valley bottoms to more than 100 inches on the mountain peaks. Snow comprises over 80 percent of the precipitation at the higher elevations and 50 percent in the valley bottoms. Elevation within the area varies from 3,000 feet in the valleys to nearly 10,000 feet at the highest peaks.

Habitat types range from warm-dry ponderosa pine/bunchgrass to cool-moist whitebark pine. Subalpine fir is the dominant habitat type. The country is known for a mixture of big, open meadows and dense forest. Uncontrolled natural fire played a large part in producing a mosaic of different even-aged communities.

About 250 wildlife species and 22 fish species are found in the wilderness and surrounding national forest lands. Native fish species include bull trout, west slope cutthroat trout, mountain whitefish, and several non-game species. Big game species include elk, mule deer, white-tailed deer, moose, Rocky Mountain goat, grizzly bear, black bear, and cougar. Endangered species include the gray wolf, bald eagle, and peregrine falcon. Threatened species include the grizzly bear.

Lakes and streams are common and dependent on snowmelt. The Middle Fork and South Fork of the Flathead River flow out of the Bob Marshall. These rivers are designated Wild and Scenic and are important for rafting, fishing, photography, and domestic and other consumptive needs. Water quality is considered excellent, although water quality has not been extensively sampled.

Air Quality Related Values

Grizzly bear and west slope cutthroat trout are the key air quality related values in this wilderness. Effects of air pollutants on forage species and other critical grizzly habitat plant communities and on meadow vegetation that could change trout habitat must to be determined. This wilderness provides one of only two major grizzly bear population centers in the lower 48 states. The cutthroat is classified as a species of special concern in Montana because of declines in abundance and distribution. It is important to the wilderness visitor for both consumptive and non-consumptive uses.

Alpine and subalpine plant communities were thought to be the most sensitive to increases in N, because they are naturally stressed ecosystems and are likely to be naturally low N-consuming systems. The Bob Marshall Wilderness is in a very clean air region. Current deposition rates for N and S are probably 1 kg/ha·yr or less for each of these elements. Therefore, increases of N and S could represent large percentage increases in the quantity of these elements. This implies that tolerable increase levels are likely to be in the low end of the Yellow Zone.

Bridger Wilderness - Wyoming

Brief Description

The Bridger Wilderness is located on the west side of the continental divide in the Wind River Mountain Range. The elevation ranges from about 8,000 to over 13,000 feet on Gannet Peak, with most of wilderness above 9,000 feet. Almost all of the area is precambrian crystalline granite except for a small section of sedimentary rock in the northwest part. The area was glaciated in the past, and still contains the largest glaciers in the continental United States. Lakes are very common (roughly 1,300) and have been stocked since 1907 with all major species of trout found in North America. Since a large portion of the wilderness is above timberline, the vegetation is primarily alpine and subalpine in character. Precipitation is primarily snow, and the annual snow pack is deep. The soils are cold, wet, and shallow with base saturation below 25%. Granite or quartz rock outcrops and talus slopes are common. Perennial streams are fed by snowmelt. Groundwater flow is minimal.

Air Quality Related Values

This wilderness was originally designated as a Primitive Area in 1930 because of its unique alpine

ecosystem, with numerous cirque lakes. These lakes are the primary AQRV needing protection.

Because of the large amount of alpine vegetation, this area is potentially very sensitive to the effects of increased nitrogen deposition. The harsh climate, shallow soils, and presumed low nitrogen uptake rates of the alpine plants suggest significant changes in growth rates and species composition under conditions of even small atmospheric N deposition. The problem would be exacerbated because the exposed bedrock in the watersheds will focus large amounts of deposition into small areas of alpine meadow.

The effects of air pollution on alpine vegetation are not well known, and the interaction of pollutants with the other severe stresses acting on alpine vegetation make the problem especially complex. To improve the knowledge base, the response of species characteristic of this wilderness to ozone exposure and N and S loading should be determined. Such determinations should be performed in natural field settings which incorporate the rigor of the alpine environment. Plant communities of special concern are the primary successional plant communities near glacial margins. The chemistry and hydrology of the snowpack needs special attention because of its crucial role in maintaining the diverse plant communities.

Superstition Wilderness - Arizona

Brief Description

The Superstition Wilderness is located south of the Mazatzal Mountains about 65 miles east of Phoenix. Elevation is approximately 1,000 to 4,000 feet. The rugged, dissected landscape that rises spectacularly out of the desert has deep canyons with steep sonoran relief. Streams are ephemeral, and there are no lakes. Hydrographs are storm-dominated.

Climate is warm semi-arid and arid, with summer convection storms and occasional winter rain. Annual precipitation is 10 to 20 inches, but can vary as much as 40 percent annually. The growing season is about 280 days. Average annual temperature is 60 to 75^{o}F.

Soils are deep, dry forest soils with base saturations above 50%. The geology includes highly diverse rock types and complex geological structures, including metamorphic, sedimentary, and intrusive and extrusive igneous rocks. The east half is proterozoic rocks that have been pervasively faulted. The west half is tertiary volcanic rocks of many different types.

Vegetation is typically open, with sonoran desert shrubs at lower elevations to interior chaparral and juniper woodland at higher elevations. Upland plants include grama grasses, creosote bush, yellow and blue palo verde, saguaro cactus, cholla cacti, ocotillo, catclaw, beargrass, agave, yucca, mesquite, mountainmahogany, hopbush, turbinella and Emory oaks, pinyon pine, and junipers.

Air Quality Related Values

Water is scarce in the Superstitions and its availability and quality are critical to sustaining the diverse faunal populations, as well as providing water for recreationists.

Riparian species are important to the visual quality of this unique wilderness, as well as furnishing perhaps one of the most valuable wildlife habitats found in the Upper Sonoran Desert. The ability of the wilderness to support the diverse wildlife species found here would be greatly diminished without riparian areas. Riparian species include cottonwood, willow, sycamore, and numerous others.

Both the number and uniqueness of Upper Sonoran Desert plants give this wilderness its special character. To lose any of these species would be a serious loss to the wilderness. Vegetation in this type is thought to be quite resistant to environmental stress, except that vegetation growing in riparian areas may be more sensitive to O_3, SO_2, and other pollutant effects.

Joyce Kilmer - Slickrock Wilderness - North Carolina, Tennessee

Brief Description

Cove and upland hardwoods are the dominant forest types typical of this warm, humid climate that has abundant, uniform precipitation. Soils range from deep, moist, and well-developed to shallow, poorly developed, and with base saturation less than 25%. The low mountains underlain by sedimentary geology vary from 2,000 to 5,300 feet in elevation. Intermittent and perennial mountain streams are common.

Air Quality Related Values

Flora, water quality, and trout fisheries all had important roles in the designation of the Joyce Kilmer-Slickrock Wilderness, and continue to be important characteristics of the wilderness, and the experiences valued by visitors.

The floral diversity is great, with more than 60 species of trees. Most of the flora is of tertiary origin, and a number of plant species are close relatives to species in eastern Asia. Wildflowers are abundant throughout the wilderness. The Joyce Kilmer Memorial

Forest portion of the wilderness has many trees over 300 years old, some more than 20 feet in circumference and 100 feet tall. This part of the wilderness is a remnant virgin forest preserved by the Forest Service since 1935. Approximately 30% of the Slickrock portion of the wilderness is also representative of a forest in its primeval condition.

The high-quality mountain streams found in the wilderness, free of sediment with clean bottoms, cool and clear, with deep pools and numerous riffles, are rare in this part of the country. These streams have been rated by the State of North Carolina as type "C Trout" and have met State standards for use as a public water supply. Slickrock Creek is a highly productive trout stream yielding about twice as much poundage per acre as neighboring streams. "Native" (reproducing naturally in the stream) brook trout are abundant in the upper reaches of Slickrock Creek. Brown and rainbow trout are prominent in the lower reaches. Little Santeelah Creek and its tributaries are habitat for brown, brook, and rainbow trout. The trout fisheries in these streams represent a major recreation opportunity in the wilderness.

The location of the Slickrock area in the southern Appalachians and the locations of some portions of the area at elevations above 4,800 feet suggest that parts of this system currently receive relatively high loadings of S and N, as well as high concentrations of O_3 (NADP 1988). Any added loading due to new sources will move pollutant levels into the Yellow Zone or above the Red Line where granting of PSD Permits is not automatic. At the high-elevation sites, minor loadings may move pollutant levels into values above the Red Line.

Slickrock's diverse forest systems of high and low elevations require that the target loading values (Green Line values) cover a somewhat higher range than other wilderness areas. Over 90% of the area is characterized by a capacity to utilize higher loadings of N because of deep, well-developed soils of moderate sulfate absorption capacity that can tolerate higher S loadings. The remaining 10% of the area is boreal forest, which receives higher loadings due to elevational effects, and has soils, tree species, and age classes of trees sensitive to low loadings of S and N. The effect of the loss of the relatively small area of high-elevation boreal forest on downslope ecosystems is currently unknown, but hydrologic and chemical disturbances might result.

Otter Creek - West Virginia and Great Gulf - New Hampshire Wildernesses

Brief Description

Otter Creek: This 20,000 acre wilderness is located in northeast West Virginia in an area with a cool, humid climate and abundant, uniform precipitation averaging 50 to 55 inches annually. It is located in the unglaciated Allegheny Plateau; mountainous, with elevations ranging between 1,800 feet near the mouth of Otter Creek, to 3,900 feet on McGowan Mountain. Otter Creek, a perennial stream, bisects the wilderness and a number of perennial tributaries occur throughout the area.

Waters are generally acid and low in productivity. There is a small native brook trout population in the upper reaches of Otter Creek, made possible by a demonstration project being conducted by the West Virginia Department of Natural Resources in which ground limestone is continuously added to Otter Creek just outside the wilderness boundary. Trout may also occur in the lower reaches of Otter Creek, below its confluence with Turkey Run, where limestone bedrock borders the stream. Otter Creek drains from a 6-acre open acid fen, and some tributaries (Yellow Creek and Moore Run) drain from open sphagnum/sedge/spruce swamps.

Soils are moderately deep to deep, with base saturation less than 35% (Utisols), and 35 to 50% (Inceptosols). They are high in iron and aluminum. Forest vegetation is a mixture of northern hardwoods and Allegheny mixed hardwoods, including a component of yellow poplar, and with red spruce at the higher elevations. Rhododendron makes up understory vegetation over extensive areas. Ground and herbaceous vegetation is somewhat depauperate over most of the wilderness compared to other low-elevation mesic sites, with the exception of limited areas of limestone bedrock in which vegetation richness increases and spring wildflowers may be abundant. The area was logged between 1890 and 1915, and 200 acres of Norway spruce was later planted on the top of Green Mountain.

Great Gulf: This gulf and its tributary gulfs were hollowed out by the action of glaciers before the last ice age. One of the distinctive features of the eastern slopes of the Presidential Range, this glacial valley between Mount Washington and the Northern Peaks is from 1,100 to 1,600 feet deep. It extends easterly from Mount Washington some 3-1/2 miles as a narrow, steep-sided gulf before broadening gradually to more open terrain. It contains a number of remarkable cascades, and the views from the walls and from points on the floor are among the best in New England.

Many of the older trees have been damaged by hurricanes, but a few scattered stands of large virgin spruce remain. A small portion of the eastern part of the area, in the lower slope type, was cut over for large spruce late in the 19th century. Northern hardwoods are the typical forest at lower elevations. Alpine plants and lichens abound above treeline. Stunted spruce and

fir provide the transition between the alpine and forested areas.

A weather observatory on the 6,262-foot summit of Mount Washington, the highest point in the Northeast, just outside the southwest corner of the wilderness, has recorded the highest wind speed (231 mph) of any weather station world-wide. Wind speeds in excess of 100 mph are not uncommon. The weather is severe most of the year, and approximates conditions encountered at a much higher latitude. The summit of Mount Washington is in the clouds approximately 55 percent of the time. The effects and extent of acid cloud/fog water (pH generally less than 3.0) are currently being studied.

Air Quality Related Values

Otter Creek: Three isolated freshwater wetlands occur, with some sphagnum vegetation most commonly associated with more northern wetland areas. A 59-acre stand of virgin red spruce and hemlock remains on Shavers Mountain. Spring ephemerals, especially on the more productive sites, provide some very desirable diversity and richness. A large number of tree, shrub, and herbaceous species within the area have known sensitivity to various air pollutants (black cherry, yellow poplar, red spruce, etc.). Change in the native plant communities and associated fauna resulting from air pollution would be undesirable.

Water quality is important for drinking water by wilderness users, and for the limited cold water fishery in Otter Creek. However, water quality in Otter Creek is being artificially improved for fishery purposes by the continuous addition of ground limestone, raising the pH and alkalinity of the stream. Therefore, water quality measurements in Otter Creek are not representative of natural conditions. Without such limestone treatment, Otter Creek water in its natural condition is acid (pH 5.0) and very low in productivity (alkalinity much less than 2 milligrams per liter, and conductivity 25 μS/cm) where it enters the wilderness. Water quality further deteriorates going downstream due to even poorer quality tributary inputs, until the neutralizing influence of limestone bedrock is encountered near the mouth of Otter Creek, where water quality improves somewhat for a fairly short reach of the stream (pH 5.8 to 6.0, alkalinity 3.1 mg/l and conductivity 31). Tributaries to Otter Creek have pH less than 4.0 and alkalinities less than 0.2 mg/l.

Great Gulf: Water quality is important for trout fisheries, and for hikers to drink and enjoy its scenic quality. Alpine flowers are rare in the Northeast and they exist in a harsh environment probably susceptible to damage from changes in soil chemistry.

Boundary Waters Canoe Area Wilderness - Minnesota

Brief Description

This second largest wilderness area (798,458 acres) under Forest Service administration sits astride the border between Minnesota and Ontario, Canada. The elevation averages 1,150 feet above sea level.

The climate is continental polar, with long cold winters and cool summers that provide only 95 frost-free days per year. Annual precipitation varies from 20 to 30 inches per year.

The bedrock underlying the Boundary Waters Canoe Wilderness is precambrian metamorphic and intrusive igneous rock, which has been glaciated only recently. The bedrock is overlaid with very thin, nutrient-poor spodosol soils of low cation exchange capacity, high in iron and aluminum, with moderately low acid neutralizing capacity, and are essentially neutral in pH.

This wilderness contains over 1,000 lakes larger than 10 acres. Three-fourths of these lakes are slightly to heavily stained a brown color from organic materials draining from the abundant peatlands in the wilderness. The pH of most of the lakes falls in the 6.6 to 8.3 range, with a mean of about 7.3. A few of the highly stained lakes have pH's as low as 5.6. Many of the lakes are sensitive, and could become acidified if acid deposition were to increase. About half have ANC's less than 130 μeq/l and base cation concentrations below 215 μeq/l. About 5% of the lakes in this wilderness have ANC's less than 50 and base cation concentrations below 140 μeq/l.

Air quality at present is very good since the BWCA sits on the eastern fringe of the Canadian and United States Great Plains, which have so far sustained little industrial development. Also, the air quality standards of the State of Minnesota are substantially more stringent than the United States federal ambient air quality standards. As a result, in 1985 the Boundary Waters Canoe Wilderness sustained a measured wet deposition of only 1.4 to 2.3 kg of nitrate nitrogen, 0.2 to 0.3 kg of ammonium nitrogen, 2.3 to 3.5 kg of sulfate, and a hydrogen ion deposition of generally less than 0.1 kg per hectare per year. The annual average pH of precipitation was about 5.0. The average ozone concentration during the growing season is about 35 ppb.

Air Quality Related Values

- o High-quality waters that support a highly diverse fishery.

- o Coniferous and mixed coniferous forests that provide the critical habitat for one of the last remaining and viable eastern timber wolf populations in the continental United States.
- o Bird populations, especially bald eagles and loons.
- o Native American pictographs and buried sites.

The relatively lower than usual Green Line and Red Line values recommended for total sulfur and nitrogen deposition in this Wilderness are justified because of the substantial sensitivity of the shallow soils, the hard crystalline bedrock, and the low alkalinity of the surface waters.

Suggested factors to be considered in making a determination of Green Line (or better) conditions:

- o Based on current knowledge of species sensitivity, modelled increases in pollutant loads will, with a high degree of certainty, result in no reduction in distribution of known pollutant sensitive tree or lesser vegetation species.
- o With a high degree of certainty, modelled increases in pollutant loads will have negligible or no impact on acid neutralizing capacity of any BWCA lake.

Suggested factors to be considered in making a determination of Red Line (or worse) conditions:

- o Based on current knowledge of species sensitivity, modelled increases in pollutant loads will result in either complete elimination or reduce distribution of at least one tree or lesser vegetation species.
- o Modelled increases in sulfate or nitrate deposition will result in complete elimination of acid neutralizing capacity from one or more lakes.

APPENDIX C. OTHER AQUATIC MEASUREMENT METHODS

Loading/Response Relationships

The acidification of lakes has been considered to be analogous to the titration of a bicarbonate solution (acid neutralizing capacity, ANC) with acidic (sulfuric acid) atmospheric deposition (Henriksen 1979). When additions of acid consume ANC, pH decreases slowly at first, then more markedly as ANC is depleted (Small et al. 1988). Acidic deposition may also increase the weathering of base cations and not result in an equivalent consumption of ANC for each equivalent of acid deposited (Henriksen 1984). Lake ANC is produced from watershed weathering and exchange reactions. These reactions generate equivalent amounts of bicarbonate and base cations. Lake ANC can also be produced from in-lake processes, such as Ca exchange with sediments, and biologically mediated removal of nitrate and sulfate (Schindler 1986). The relative importance of in-lake versus watershed sources of alkalinity and the relationship between acid deposition and enhanced weathering of base cations is known for only a few ecosystems. These additional mechanisms, which act to reduce the effect of acidic deposition, cannot be included in a conservative estimate of the relationship between deposition amount and ecosystem impacts.

Our approach is analogous to the Henriksen empirical model where deposition amount, lake sensitivity (sum of base cations), and the results of lakes surveys are used to empirically derive, for lakes of a given sensitivity and deposition level, where the system will experience ANC decline and pH depression. We assume that in-lake alkalinity generation and enhanced weathering of base cations is negligible.

Graph Construction

Figures C-1 and C-2 show, for various deposition levels, the concentrations of non-marine Ca+Mg+K+Na in lakes having ANC of 10 to 25 µeq/l and pH values of about 5.9 to 6.2, and in lakes with ANC between -20 and -5 and pH of about 4.8 to 5.2. Figure C-1 shows the Green Lines for these. The Green Lines indicate the deposition level below which lakes with various base cation concentrations should maintain ANC of at least 10 to 25 µeq/l and pH of at least 5.8 to 6.2. Figure C-2 shows Red Lines. If subjected to a particular deposition level, lakes with base cation concentrations less than those indicated by the Red Lines can be expected to become acidic with ANC falling below zero and pH reaching 5.2 or less.

The graphs are based on the assumption that, while lake HCO_3 decreases and is replaced by SO_4 in response to increasing S deposition, base cation concentrations do not change. In fact, as deposition increases, mineral weathering of base cations from the watershed may increase somewhat (Henriksen 1984). As a result, lakes with a given base cation concentration may be able to withstand a somewhat greater increase in S deposition than indicated by the nomographs. In-lake alkalinity production may also reduce the impact of S deposition (Schindler 1986). Because these effects are uncertain in magnitude and probably do not occur in all lakes, we have taken the conservative approach of protecting the lakes and have assumed that these processes are not significant.

The amount of runoff relative to the amount of precipitation on a watershed affects how lake chemistry responds to acid loadings. As more precipitation is lost to evapotranspiration and less is yielded as runoff, acid deposition is, in effect, concentrated, and its impact on a lake is greater. Consequently, the graphs show several Red and Green Lines for various amounts of runoff, expressed as percentages of annual precipitation.

N deposition is included for very low ANC (<50 µeq/l) waters in the western United States. The rationale for including N is based on observations that most N deposited on a watershed is retained in the watershed. At most, about 20% can be seen in surface waters. This is explained in the text. Deposition loading was determined as outlined in the surface water sensitivity section, page 12. Essentially, total deposition was determined by combining wet deposition data with dry deposition estimates. In the east, dry deposition was estimated to be 30% of wet deposition, while in the west dry deposition was assumed to be zero.

Within about 125 miles of the sea coast, precipitation contains significant amounts of sodium, magnesium, chloride, and sulfate and lesser amounts of other ions of marine origin. These ions increase the base cation concentration of lakes in these areas without adding HCO_3 or ANC. To correct for this effect, we assume that all chloride (Cl) in such lake water is from marine sources, and subtract from the base cation concentration an amount in proportion to the relative concentrations of Cl and base cation in seawater (Hem 1970).

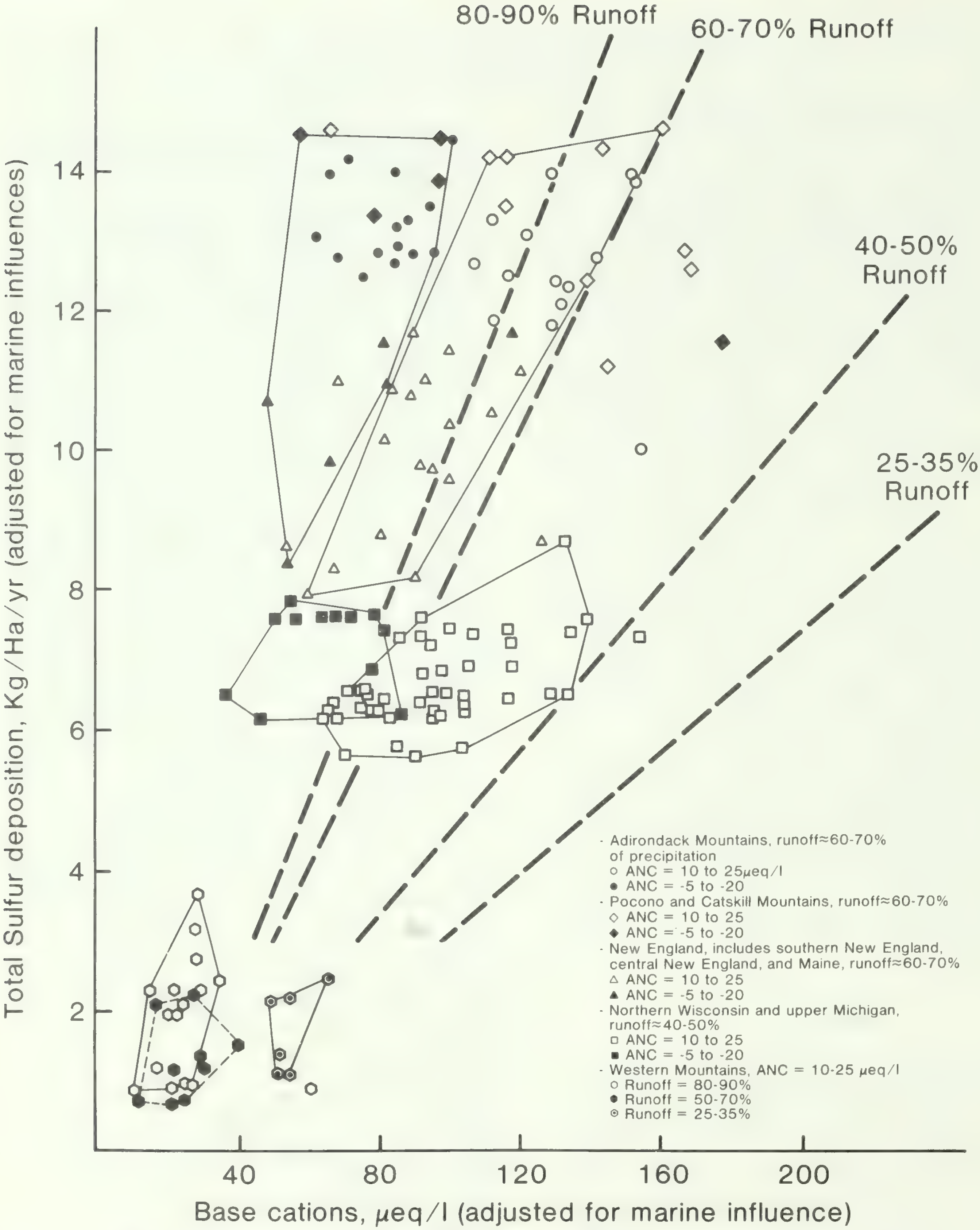


Figure C-1.--Base cations/deposition relationship for Green Lines. Lakes to the right of the appropriate runoff lines are not considered to be acidic. (Data from Kanciruk et al. 1986 and Eilers et al. 1987.)

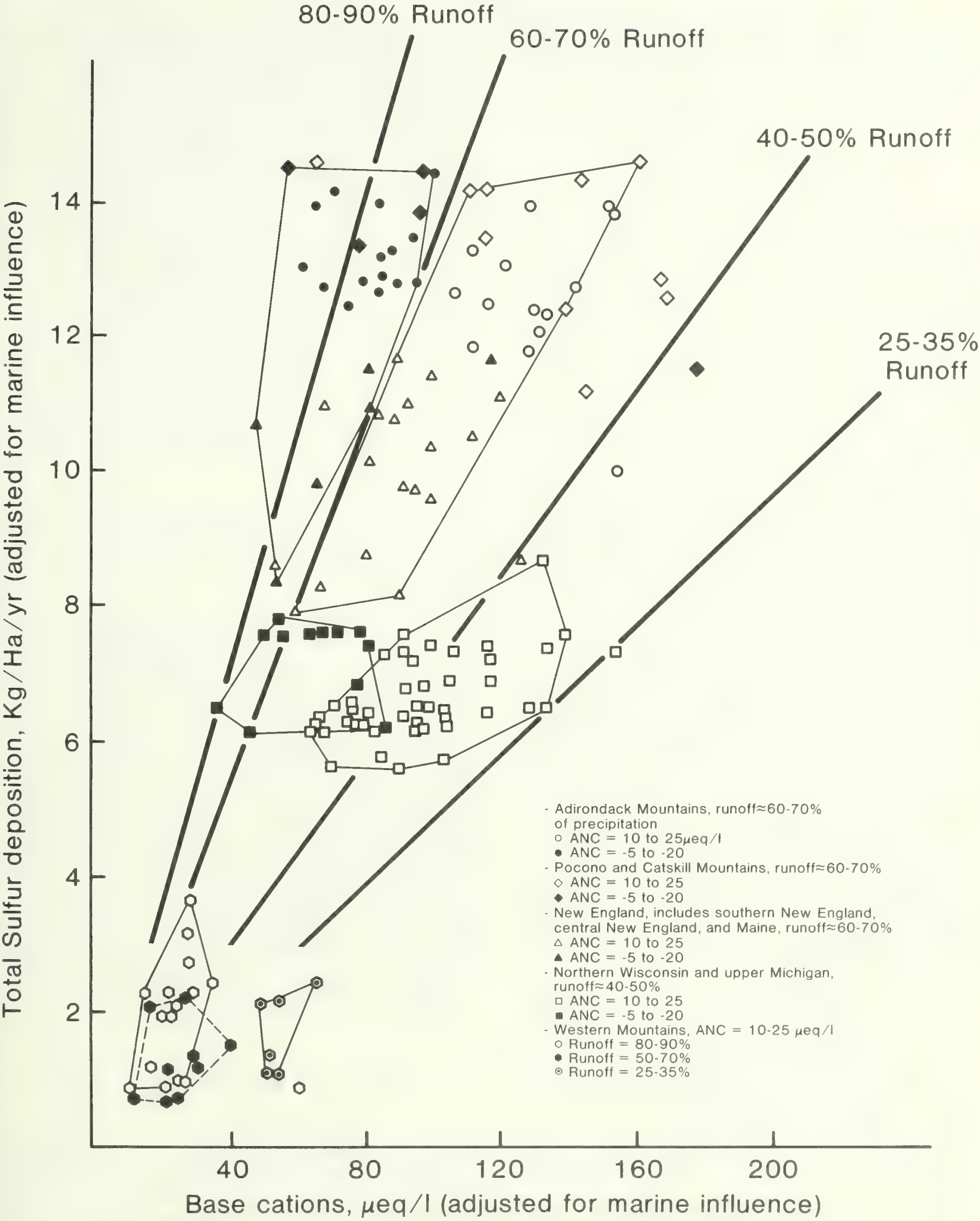


Figure C-2.--Base cations/deposition relationship for Red Lines. Lakes to the left of the appropriate runoff lines are likely acidic. (Data from Kanciruk et al. 1986 and Eilers et al. 1987.)

Inland lakes generally have low concentrations of Cl and Cl-associated base cations, but natural geologic sources and contamination by road salt may increase them. The base cation concentration of these lakes also must be corrected for this influence. This is done by assuming:

$$\text{Non-marine Ca+Mg+K+Na} = \text{Total Ca+Mg+K+Na} - (\text{Cl} \times 1.115)$$

Concentrations of all ions are expressed in µeq/l.

Lake SO_4 generally increases with increasing S deposition, but natural geologic sources also contribute variable amounts of SO_4 to lakes (Loranger and Brakke 1988, Eilers et al. 1987). Base cations associated with geologic SO_4 add significant variability to the ANC:base cation relationship. In figures C-1 and C-2, much of the scattering of data points for any given deposition level and runoff percentage can be attributed to geologic SO_4 and associated base cations.

This approach is similar to the so-called Hendriksen model, which has been shown to have limitations (Reuss et al. 1986, Vertucci in press). However, the Red Line values used here are based on an empirical fit to the data on acidified lakes. The Green Line values essentially represent a simple balance of increased sulfate (and nitrate) against ANC. This is an approximation that Wright (1988), among others, suggests can be improved by the introduction of a factor "f" representing the ratio of change in base cation concentration to net sulfate (that attributable to anthropogenic sources). The model here assumes f to be zero. A nonzero f would make the Green Lines steeper. Since this is intended as a worst case screening technique that errs on the side of conservatism, and actual f values are unknown, we felt it was appropriate to use an f factor of zero.

In cases where little cation data exist, conductivity was considered as an alternate measure of sensitivity. Since conductivity is easily and cheaply measured in the field, conductivity data may be more widely available for surface waters than are cation data. Easy and cheap don't necessarily equate with accurate, however, and field conductivity data must be closely screened to ensure reliability. Electrical conductivity (usually expressed as µSiemens/cm at 25 degrees C) is a measure of the total amount of ions dissolved in the water. Consequently, conductivity is related to the sum of the base cations and anions. Waters that are inherently sensitive to acid deposition have little buffering or acid neutralizing capacity, low concentrations of base cations, and low conductivity.

Figures C-3 and C-4 are similar to C-1 and C-2, but show lake conductivity in place of base cation concentration as a measure of lake sensitivity. Because conductivity is an indicator of the total concentration of ions dissolved in the waters, it is used as a substitute for the base cation concentration. Since the contribution of SO_4 and HCO_3 to conductivity are about the same, we assume that the conductivity of a lake does not change with increasing S deposition. As with figures C-1 and C-2, we ignore the fact that base cations, and consequently conductivity, may increase somewhat at greater deposition levels, due to increased mineral weathering.

As with base cations, conductivity must be corrected for marine influences. This correction is even more critical for conductivity, because conductivity is influenced not only by the ocean-derived base cations, but also by the Cl and SO_4. In addition to the adjustments for marine contributions, conductivity must also be corrected for hydrogen ion (pH) influences. In acidic waters, hydrogen contributes heavily to conductivity, and this contribution must be subtracted. All the lake conductivity data in figures C-3 and C-4 are corrected for both pH and marine influences. This is done by assuming:

$$\text{Non-marine conductivity} = \text{measured conductivity} - (\text{Cl} \times 0.1422)$$

with Cl expressed in µeq/l and conductivity in µSiemens.

$$\text{Adjusted conductivity} = \text{measured conductivity} - (\text{H} \times 0.34965)$$

where H is the hydrogen ion concentration in µeq/l (H=10 raised to the -pH power, then that quantity multiplied by 1,000,000).

Differences in natural sources of SO_4 add much variation to the ANC:conductivity relationship. This effect is greater than that on ANC:base cations because both SO_4 and the associated base cations contribute to conductivity. For any particular deposition level and runoff percentage, the scatter among the data points and the overlap between groups of acidic and non-acidic lakes is greater in figures C-3 and C-4 than in C-1 and C-2. Therefore, base cations rather than conductivity should be used as a measure of lake sensitivity where cation data are available. Conductivity is useful as a rough tool to separate lakes into non-sensitive and possibly sensitive groups.

Detailed Information Needs

Surface water chemistry data can be collected by means of special purpose surveys, by census, or by estimating values based on previous surveys in similar geographic terrains. As an example of the last approach, an approximate characterization of the surface water chemistry of seven of the nine wilderness ecosystem types is presented in table C-1.

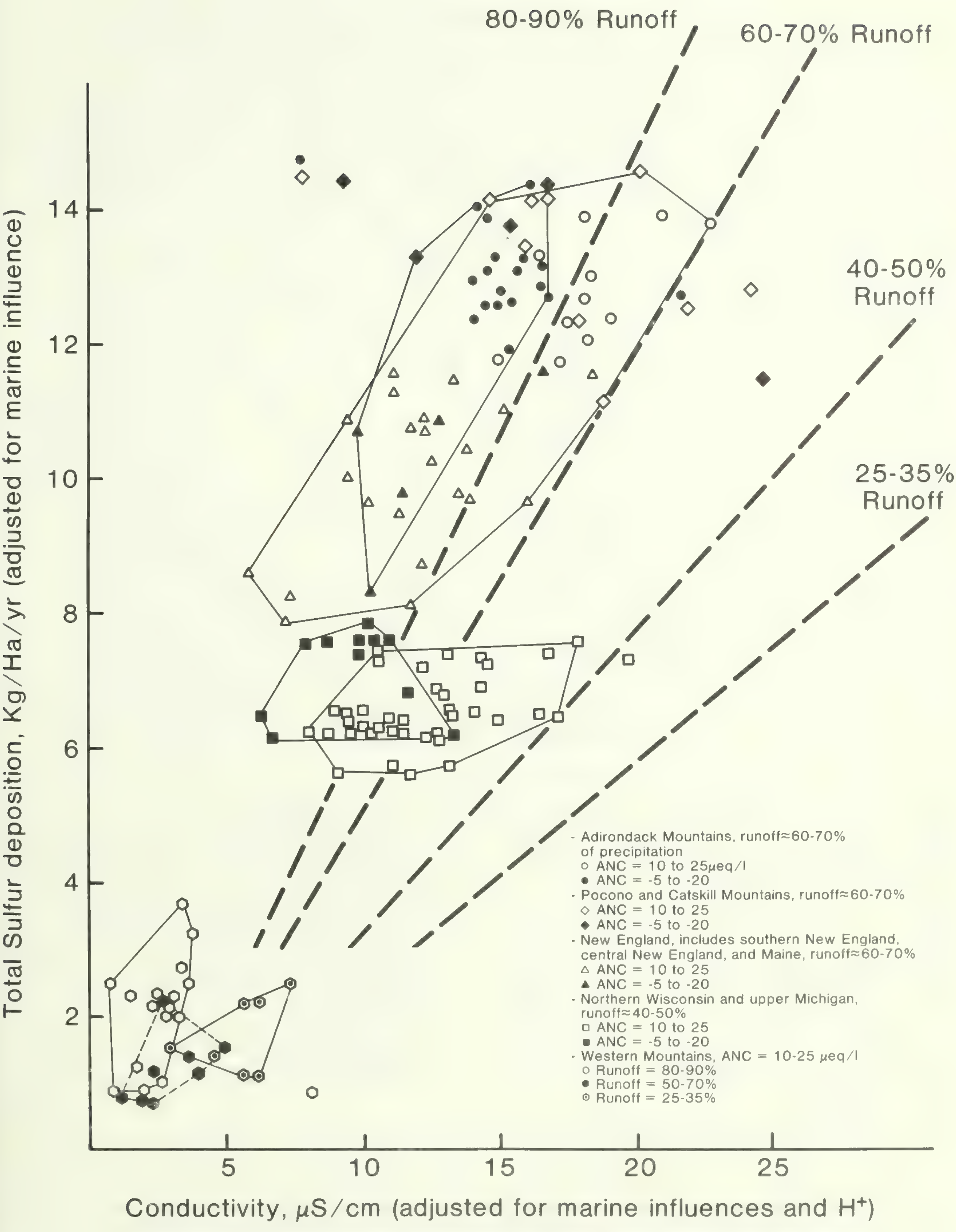


Figure C-3.--Conductivity/deposition relationships for Green Lines. Lakes to the right of the appropriate runoff lines are not considered acidic. (Data from Kanciruk et al. 1986 and Eilers et al. 1987.)

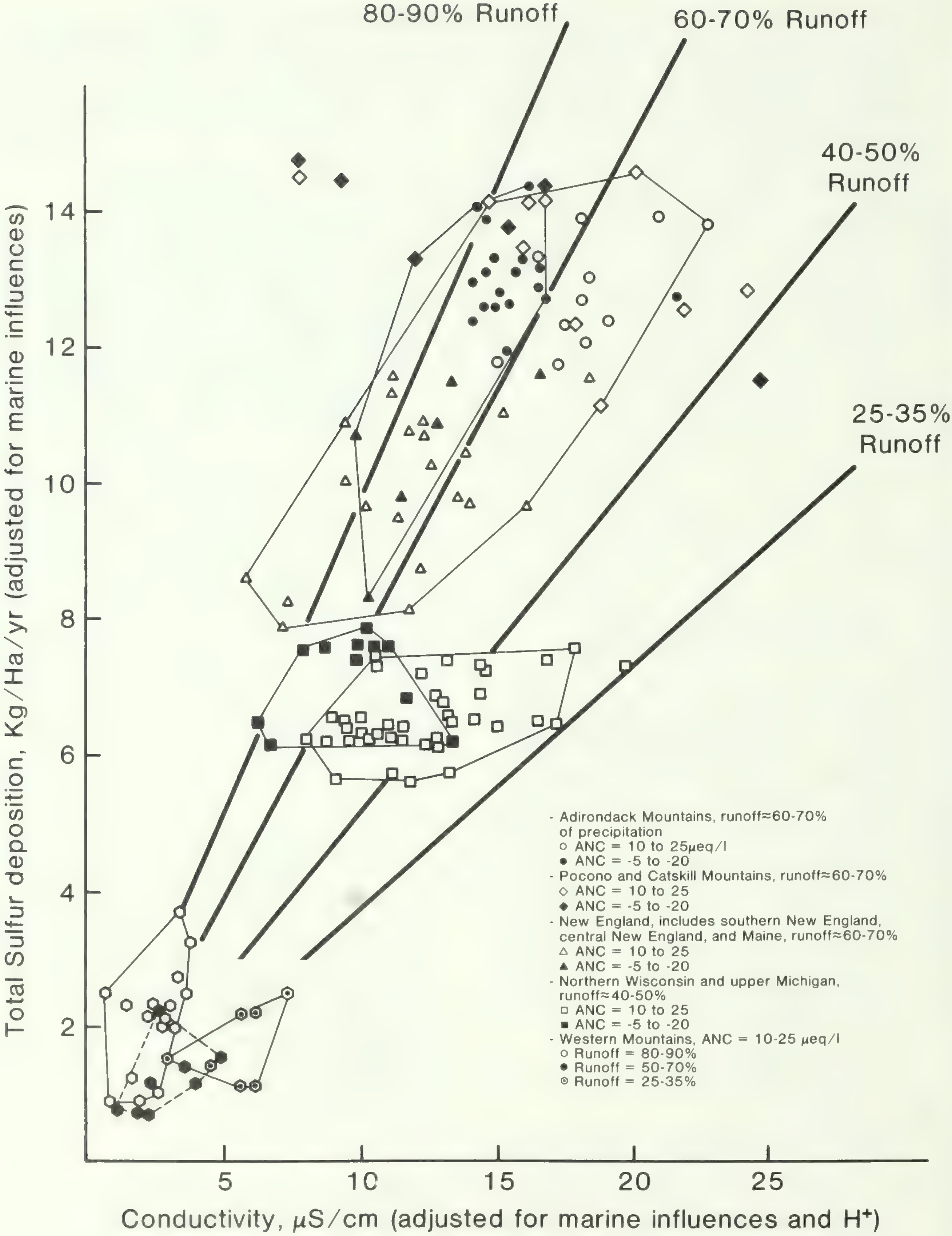


Figure C-4.--Conductivity/deposition relationships for Red Lines. Lakes to the left of the appropriate runoff lines are likely acidic. (Data from Kanciruk et al. 1986 and Eilers et al. 1987.)

Table C-1.--Conductivity and neutralizing capacity, and pH statistics for geographic regions represented by seven wilderness ecosystem types.

Wilderness area and NSWS region	Conductivity			ANC			pH		
	Min.	Q_1	Med.	Min.	Q_1	Med.	Min.	Q_1	Med.
		μS/cm			μeq/l				
Alpine Lakes, Glacier Peak (PNW[1])	>2	9/6	14/4	>4	54/52	196/105	>5.8	6.6	6.9
Hoover, Dome Land (SNM[2])	>2	5	8	7/13	34	60	>5.8	6.6	7.0
Bob Marshall (NR[3])	>3	9	39	72	77	342	6.3	6.9	7.1
Bridger (ALP[4])	>7	12	15	39	74	109	>5.8	6.9	7.1
Joyce Kilmer, Slickrock (EHW[5])	10	14	21	16	87	120	6.4	6.8	7.0
Otter Creek, Great Gulf (NH[6])	19	33/22	69/35	-48	20/52	110/119	4.4	5.7/6.3	6.6/6.8
Boundary Waters Canoe Water Area (C[7])	18	22	30	34	98	185	5.6	6.6	6.9

1WLS Pacific NW, Middle Washington and Wenatchee Mtns.
2WLS California, Sierra Nevada.
3WLS Northern Rockies, Lewis Range.
4WLS Central Rockies, Wind River.
5NSS Southern Blue Ridge.
6NSS N. Appalachians, ELS C. New England.
7ELS NE Minnesota.

WLS = EPA Western Lake Survey.
ELS = EPA Eastern Lake Survey.
NSS = National Stream Survey.

These data are based on the National Surface Water Survey (NSWS), which measured the chemistry of a large statistical sample of lakes and streams in regions of the United States. expected to have surface water with low acid neutralizing capacity. In several cases (such as the Bridger Wilderness), many lakes were sampled. In most cases, however, only a few lakes or streams were actually included. As an approximation, the chemical data in table C-1 were aggregated to include the geographic units nearest to exact wilderness that approximate the geology of the corresponding regions, based on the NSWS data. No data were collected in southern California nor in Arizona.

Half of the lakes or streams in each region are expected to fall below the median value for each region. Twenty percent of the systems are expected to fall below the first quintile (Q_1). Minimum values represent the lowest value observed in the sample, and do not necessarily represent the lowest lake or stream in the region. Lake chemistry was measured following fall overturn. Stream chemistry was sampled in the spring between snowmelt and leaf-out, avoiding rain storms. Streams affected by acid mine drainage and polluted lakes were avoided.

These data are statistically valid randomly selected samples of water quality in all areas. To obtain a better estimate of the true chemistry distributions in a particular wilderness, a random sample of approximately 50 lakes can generally give acceptable confidence bounds if the area is not too heterogeneous. If 50 represents less than 5% of the total population of lakes, or if the area is highly diverse, a larger sample size may be needed to reduce uncertainties in the estimates. Field sampling, while inexpensive, must follow protocols for wilderness areas (Fox et al. 1987).

Annual runoff can be calculated from estimated precipitation and evapotranspiration measurements on site, or measured at a gauged stream site in the region

of interest. In the absence of such data, published values of mean annual runoff from state and federal agencies in state water atlases and other publications can be used. Annual variations in runoff are not a significant concern in using figure 1, provided long term data are available.

Dry deposition of sulfate and nitrate are often estimated from obtaining wet deposition data from the nearest National Acid Deposition Program (NADP) site. As a rule of thumb, in rural areas removed from point sources of pollution, dry deposition of sulfur can be assumed to equal 30% of the wet deposition value. Dry nitrogen deposition may be somewhat greater than the wet value. These factors are subject to considerable local variations, including impaction of particles on dry surfaces, and adsorption of gaseous species (SO_2 and HNO_3) by moist surfaces, including lakes and the open stomata of vegetation. If air concentration data of S and N are available, dry deposition can be calculated using assumed values of deposition velocity taken from the Air Resource Handbook. Still more desirable are dry deposition estimates from a nearby NDDN (National Dry Deposition Network) site. These are currently being installed throughout the United States.

Conversion of Deposition Values

Deposition loadings are presented in kg/ha-yr of S and N. Deposition measurements are often reported as deposition of SO_4 and NO_3 in mg/m^2/yr. Land managers may also be familiar with applications of S and N in lb/A/yr. The following conversion factors may be useful:

Multiply S deposition by 3.0 to determine SO_4 deposition

Multiply N deposition by 4.43 to determine NO_3 deposition

Multiply kg/ha by 0.89 to determine lb/A

Multiply kg/ha by 100 to determine mg/m^2

Multiply kg/ha by 0.1 to determine g/m$_2$

To convert from mg/l to µeq/l, multiply mg/l of Ca by 49.90, Mg by 83.26, K by 25.57, Na by 43.50, Cl by 28.21, and SO_4 by 20.82.

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U.S. Department of Agriculture
Forest Service

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Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-169

Biology and Management of Dwarf Mistletoe in Lodgepole Pine in the Rocky Mountains

Frank G. Hawksworth and David W. Johnson

Dedication

Oscar J. Dooling, 1931–1987

This work is dedicated to the memory of Oscar J. Dooling, long-time Forest Pathologist with the Forest Pest Management Unit, USDA Forest Service Regional office in Missoula, Montana. Oscar's strong interest and helpfulness in providing on-the-ground forest disease assistance for foresters throughout the Rocky Mountains was well known. He recognized the need for and encouraged us to write this compilation on lodgepole pine dwarf mistletoe as an aid to forest managers for controlling this widespread pest.

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April 1989

Biology and Management of Dwarf Mistletoe in Lodgepole Pine in the Rocky Mountains

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Abstract

This publication synthesizes the vast literature on lodgepole pine dwarf mistletoe (*Arceuthobium americanum*) and adds some new information on biology of the parasite. Although dwarf mistletoe has been recognized as a serious parasite of lodgepole pine for more than 75 years, its routine operational control through forest management has been primarily a development over the past two decades. This report discusses silvicultural control of dwarf mistletoe in various types of stands where fiber production is the primary goal, and also in forests used mainly for recreation.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Biology and Management of Dwarf Mistletoe in Lodgepole Pine in the Rocky Mountains

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INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl.) is the most widely distributed conifer in western North America. It ranges from the central Yukon to Baja California, and east to Alberta and South Dakota (Critchfield and Little 1966). The commercial area of lodgepole pine is nearly 63 million acres (25.5 million ha), with more than 50% of it in British Columbia (McDougal 1975, Wellner 1975). The lodgepole pine growing stock is about 82 billion ft^3 (2.32 billion m^3), and its annual harvest is about 530 million ft^3 (15 million m^3). About one-third of the growing stock and one-fourth of the annual lodgepole pine harvest are in the United States, with most of it in the Rocky Mountain states of Montana, Idaho, Wyoming, and Colorado.

An excellent synthesis of information on lodgepole pine and its management appears in the proceedings of a recent symposium (Baumgartner et al. 1985). Other recent references that contain much useful information on lodgepole pine are a bibliography of the literature on the species (Grewal 1987) and symposia proceedings on subalpine forests of the Rocky Mountains (Troendle et al. 1987) and future forests of the Mountain West (Schmidt 1988).

Lodgepole pine has four geographic subspecies (Wheeler and Critchfield 1985):

- *P. contorta* ssp. *contorta* (shore pine)
- *P. contorta* ssp. *murrayana* (Balf.) Critchfield (Sierra-Cascade lodgepole pine)
- *P. contorta* ssp. *bolander* (Parl.) Critchfield (Mendocino White Plains shore pine)
- *P. contorta* ssp. *latifolia* (Engelm. ex Wats.) Critchfield (Rocky Mountain lodgepole pine).

The last is the most widespread subspecies and is the type referred to throughout the rest of this paper.

Lodgepole pine is plagued by many pests, the two most important of which are dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) and mountain pine beetle (*Dendroctonus ponderosae* Hopk.). The former is the subject of this paper; the latter has been the subject of recent reviews (e.g., McGregor and Cole 1985).

Dwarf mistletoe is the most widespread and damaging disease agent in lodgepole pine throughout its range, and has been recognized as a serious pest for more than 70 years (Mason 1915). Because of the importance and wide distribution of *Arceuthobium americanum*, both in the United States and Canada, more literature has been written on it than for any other dwarf mistletoe. This report synthesizes information from the most significant of the more than 1,100 publications on the species that relate to its biology, ecology, damage, and silvicultural control, and also includes some new information.

HOSTS, DISTRIBUTION, AND ABUNDANCE

Hosts

Lodgepole pine is the primary host of *A. americanum* (table 1). Although no susceptibility tests have been made, observations suggest that the Pacific Coast subspecies (*P. contorta* ssp. *murrayana*) and the Interior subspecies (*P. contorta* ssp. *latifolia*) are about equally susceptible. Shore pine (ssp. *contorta*) also is susceptible, but there are only a few areas in north-coastal British Columbia where this tree occurs within the range of *A. americanum* (Smith and Wass 1979).

Arceuthobium americanum also parasitizes jack pine (*Pinus banksiana* Lamb.) from northern Alberta to extreme western Ontario. The dwarf mistletoe also attacks the lodgepole pine-jack pine hybrid in northern Alberta (Hawksworth and Wiens 1972). Some secondary, occasional, rare hosts and immune tree species appear in table 1.

Distribution

Arceuthobium americanum is one of the most widely distributed dwarf mistletoes in North America, ranging

Table 1.—Natural hosts of *Arceuthobium americanum* in western North America (adapted from Hawksworth 1975).

Principal	*Pinus contorta* ssp. *latifolia* *Pinus contorta* ssp. *murrayana* *Pinus contorta* ssp. *contorta*[1]
Secondary	*Pinus ponderosa* var. *scopulorum*
Occasional	*Pinus albicaulis* *Pinus flexilis* *Pinus ponderosa* var. *ponderosa*
Rare	*Picea glauca* *Picea engelmannii* *Picea pungens* *Pinus aristata* *Pinus attenuata*[2] *Pseudotsuga menziesii*[3]
Immune	*Abies concolor* *Abies grandis* *Abies lasiocarpa* var. *lasiocarpa* *Abies magnifica* *Larix occidentalis* *Tsuga mertensiana*

[1]*Known only from a few areas in coastal British Columbia on this host.*

[2]*Unconfirmed reports in southwestern Oregon.*

[3]*Extremely rare on this host; known from only one locality in northern Utah (Hawksworth and Wiens 1972), one in Alberta (Muir 1973), and one in Colorado (R. L. Mathiasen collection in USDA Forest Service Forest Pathology Herbarium in Fort Collins, CO).*

from northern Alberta (nearly 60° N lat.) to central Colorado (38° N lat.) and central California (35° N lat.) on lodgepole pine, and on jack pine from Alberta to western Ontario (Hawksworth and Wiens 1972) (fig. 1). Dwarf mistletoe occurs essentially throughout the range of *Pinus contorta*, with the notable exception of stands west of the Pacific Crest in Oregon and Washington.

Abundance

Recent surveys indicate the magnitude of the lodgepole pine dwarf mistletoe problem in the Rocky Mountains (table 2). Surveys in the Intermountain Region (southern Idaho, western Wyoming, and Utah) show that about 60% of the lodgepole pine stands are affected. For the Rocky Mountain Region (Colorado and Wyoming east of the Continental Divide), the comparable figure is 51%. Infection in lodgepole pine stands in Montana National Forests ranges from 18% to 52% and averages 35%.

BIOLOGY

The Mistletoe Plant

Shoots

Arceuthobium americanum plants are dioecious and typically 5 to 8 cm tall (Hawksworth and Wiens 1972)

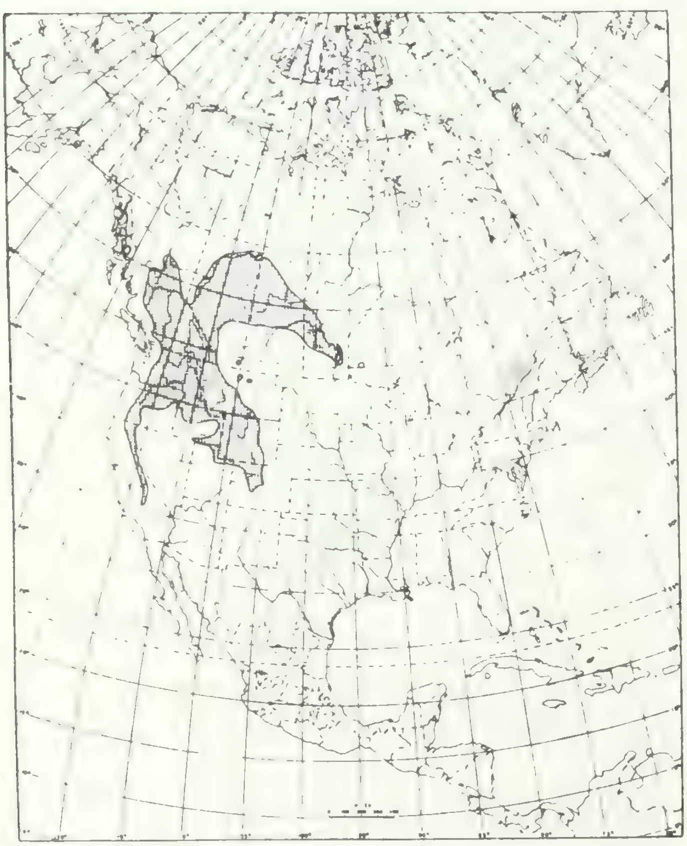


Figure 1.—General distribution of lodgepole pine dwarf mistletoe in North America.

Table 2.—Incidence of lodgepole pine dwarf mistletoe by National Forests in the Rocky Mountains.

Region, State, National Forest	Incidence of *A. americanum* in lodgepole pine type stands (% affected)
Northern Rocky Mountain Region	
MONTANA[1]	
Beaverhead N.F.	52
Bitterroot N.F.	44
Custer N.F.	28
Deerlodge N.F.	47
Flathead N.F.	18
Gallatin N.F.	42
Helena N.F.	35
Kootenai N.F.	22
Lewis and Clark N.F.	37
Lolo N.F.	23
Subtotal	35
IDAHO[2]	
Nez Perce N.F.	27
Idaho Panhandle N.F.	27
Clearwater N.F.	8
Subtotal	21
Intermountain Region[3]	
CALIFORNIA	
Toiyabe N.F.	17
IDAHO	
Boise N.F.	57
Caribou N.F.	68
Challis N.F.	70
Payette N.F.	50
Salmon N.F.	59
Sawtooth N.F.	71
Targhee N.F.	79
UTAH	
Ashley N.F.	58
Uinta N.F.	28
Wasatch N.F.	34
WYOMING	
Bridger-Teton N.F.	67
Subtotal	60
Rocky Mountain Region[4]	
COLORADO	
Arapaho-Roosevelt N.F.	48
Grand Mesa-Uncompaghre-Gunnison N.F.	52
Pike-San Isabel N.F.	43
Routt N.F.	52
White River N.F.	36
WYOMING	
Bighorn N.F.	36
Medicine Bow N.F.	60
Shoshone N.F.	64
Subtotal	51

[1]*Data from Dooling and Eder (1981).*
[2]*Estimates provided by O. J. Dooling (personal communication, 1985).*
[3]*Data from Hoffman and Hobbs (1985).*
[4]*Data from Johnson et al. (1981).*

(Plate I). The shoots are leafless, with whorled branching. Male and female plants usually occur in a ratio of 1:1. Female shoots tend to be greenish, while male shoots are typically more yellow, especially in the spring.

Male Flowers

The male flower has three or four segments, each with a single sessile anther (Plate I). The pollen grains are globose, spinulose, and about 20–25 microns in diameter. A nectary is found at the center of each flower. *A. americanum* flowers in the spring; flowering begins in late March and lasts until late June, but with a peak usually between early May and mid-June (Hawksworth 1965) (fig. 2).

Female Flowers and Fruits

The female flowers of *Arceuthobium* are small and inconspicuous. The perianth segment is two-parted (Plate I). The flowers are pollinated in the spring, and the fruits take 15–17 months to develop before they mature in late summer of the second season. The pollinated fruits attain about one-third of their final size during the first summer. As the fruits mature, the pedicel becomes elongated so that the original tip of the fruit is oriented downward (Plate I). At maturity, the single seed is forcibly ejected from the fruit at initial velocities up to 60 miles/hr (2,600 cm/sec) (Hinds and Hawksworth 1965). Seeds are dispersed for distances up to 50 feet (15 m), but typically for 15 feet (5 m) or less.

The period of seed dispersal lasts about 8 weeks, but is usually only 3–4 weeks at a given locality and year.

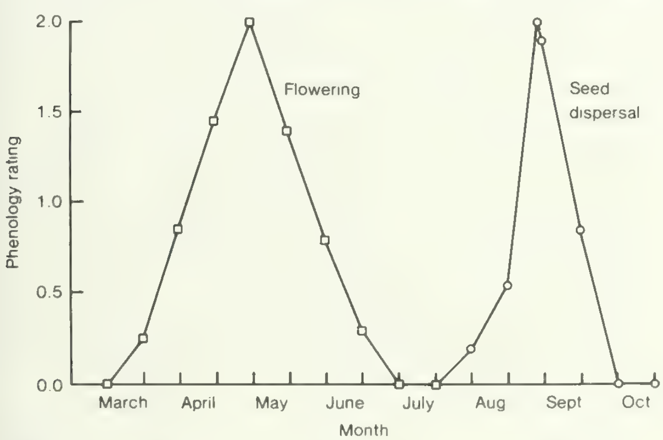


Figure 2.—Phenology of flowering and seed dispersal of *Arceuthobium americanum*. Based on about 240 populations from throughout the range of lodgepole pine. For phenological studies, we use a 5-point phenology rating system to classify individual populations:

0 - Flowering (or seed dispersal) not yet begun;
1 - " " " " begun but not at peak;
2 - " " " " near peak;
3 - " " " " past peak;
4 - " " " " over.

The results are then summarized by 2-week periods. Then a cumulative graph (0-4) is plotted; for this figure, the portion beyond 2.0 was inverted to show the peak, thus 3.0 (past peak) is here plotted as 1.0 and 4.0 (flowering and seed dispersal over) plotted as 0.0.

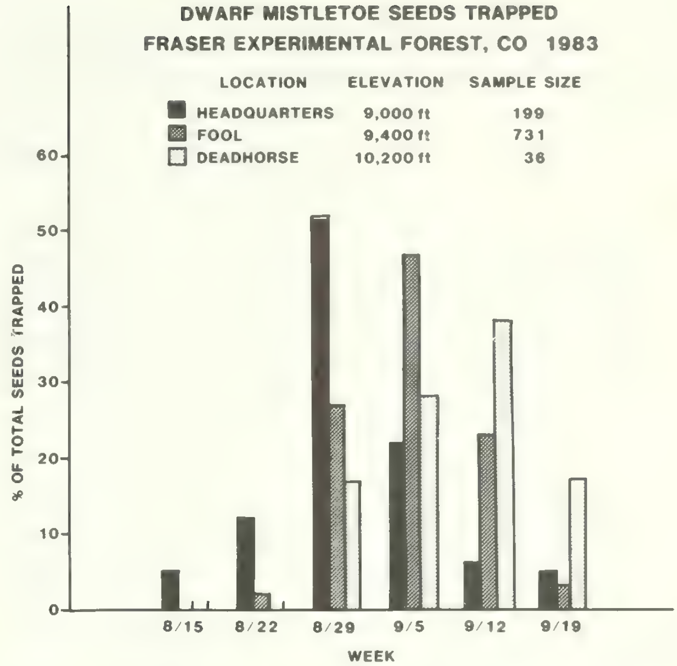


Figure 3.—Phenology of seed dispersal of lodgepole pine dwarf mistletoe at three elevations in the Fraser Experimental Forest, Colorado (Nicholls et al. 1984).

Seed dispersal begins in late July and lasts until early October, but with peaks usually between late August and late September (fig. 2). At a given locality, seed dispersal begins first at lower elevations. For example, on the Fraser Experimental Forest in Colorado, peak dispersal was about 1 week later for each 500-foot (150-m) increase in elevation (fig. 3) (Nicholls et al. 1984).

Pollination

Although dwarf mistletoes have the flower and pollen characteristics of insect-pollinated plants (limited pollen production, spinulose pollen, pollen dispersed in clusters, nectar, and odor production) (Hawksworth and Wiens 1972), their pollen is also disseminated by wind (Gilbert and Punter 1984, Player 1984). Penfield et al. (1976) concluded from a study of *A. americanum* and two other dwarf mistletoes in northern Colorado that these species are primarily insect-pollinated. About 20 species of pollen-bearing insects were found on *A. americanum*, the most important of which were an ant (*Formica fusca* L.) and a fly (*Philygra debilis* Loew.). Gilbert and Punter (1984) concluded that both insects and wind are involved in pollination of *A. americanum* on jack pine in Manitoba. Wind-borne pollen was found up to 1,300 feet (400 m) from the closest pollen source. Coppola (1988) found *A. americanum* pollen up to 1,680 feet (512 m) from the closest male plants in the Roosevelt National Forest in northern Colorado.

Life Cycle

A generalized life cycle of *A. americanum* appears in figure 4. The time from seed dispersal to infection, establishment of new plants, and flowering averages

about 6 years. The time from seed dispersal to production of the first shoots ranges from 2 to 8 years, with about two-thirds appearing in the third and fourth years (fig. 5).

Host Reactions

Dwarf mistletoes typically develop fusiform swellings on the host at the site of the infection (Plate II). These swellings are caused by increased growth in both host cortex and xylem. If infection occurs on relatively young host tissues, dormant host buds are stimulated, and dense masses of branches called witches' brooms subsequently develop (Plate III). Lodgepole pine dwarf mistletoe typically forms a unique type of witches' broom; these are systemic in that the root system of the parasite is incorporated into the apical meristem of the bud of the host twig (Hawksworth and Wiens 1972, Kuijt 1960). All branches on the broom are thus parasitized by the mistletoe. On these systemic brooms, clusters of the mistletoe shoots are formed at the interwhorl between annual growth segments.

Seed Dispersal

Few studies have been conducted on the distance of seed dispersal of *A. americanum*. Muir (1977) measured dispersal from two 10-foot (3-m) tall lodgepole pines in Alberta, where the number of seeds dispersed decreased logarithmically with increasing distance from the source trees. The maximum distance of seed flight from the crown circumference was 13 feet (4 m) from one tree, and 18 feet (5.5 m) from the other.

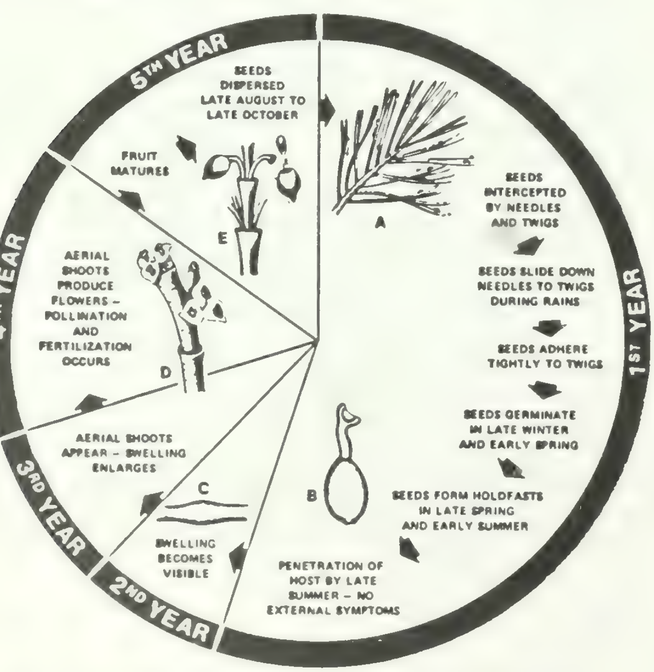


Figure 4.—Generalized life cycle of *Arceuthobium americanum* on lodgepole pine. Adapted, with permission, from Baranyay and Smith (1972).

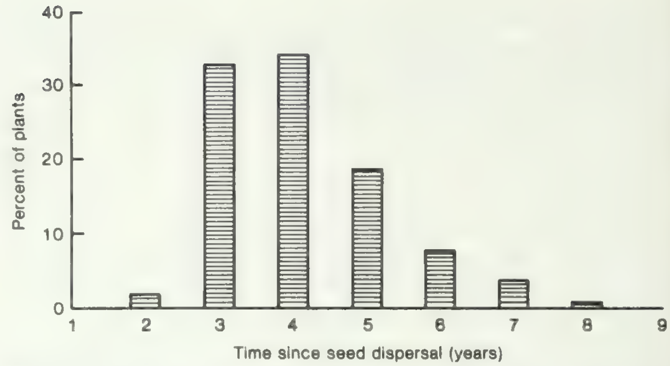


Figure 5.—Length of the incubation period from time of seed dispersal to appearance of first shoots. Basis: 469 plants on the Roosevelt National Forest, Colorado.

Distances of spread of *A. americanum* from larger trees is greater than for small trees. Average distances of seed dispersal from overstory trees to adjacent reproduction ranged from 22 to 28 feet (6.7–8.5 m) (Hawksworth 1958b, Hawksworth and Graham 1963, Muir 1970). Mean distance of spread from stands in Alberta was 28 feet (8.5 m) and up to 45 feet (13.7 m) from isolated residual trees (Muir 1970). Perhaps wind is more significant in dispersal from isolated trees than along stand edges.

Spread and Intensification

Local Spread

The rates of spread of *A. americanum* are fastest from overstory trees to adjacent reproduction. Spread through even-aged stands is considerably slower. Hawksworth (1958b) studied rates of spread in Colorado and Wyoming (fig. 6). In 20-year-old stands adjacent to an infested overstory stand, dwarf mistletoe progressed less than 30 feet (9 m) into the reproduction. In 30-year-old reproduction, the parasite spread 30 to 45 feet (9–14 m), depending primarily on the density of the young stand. Spread through young lodgepole pine is 1.5 times greater in stands in which the canopy has not closed than in stands with closed canopies. In 20-year-old stands, about 10% of the trees within 30 feet (9 m) of an infested mature stand were infected. In 30-year-old stands, infection in this zone approached 35%.

Beyond 30 feet from the residual stands, average rate of spread through even-aged open stands was 1.7 feet (0.5 m) per year, and 1.2 feet (0.4 m) per year in dense stands. Hawksworth and Graham (1963) conducted a more detailed study of overstory-understory spread in lodgepole pine in Colorado, Wyoming, and Montana. The average proportion of trees visibly infected in reproduction 10, 15, 20, and 25 years old was 3%, 9%, 18%, and 32%, respectively (fig. 7). Thus, the proportion of trees visibly infected essentially doubled each 5 years between ages 10 and 25. The amount of dwarf mistletoe was highest in reproduction on the better sites. Dissections of the oldest infections on the plots showed that 84% were infected before they were 11 years old. None

of the factors measured that were associated with the residual stand (e.g., stand mistletoe rating, tree height, etc.) or with the location of the study areas were correlated with amounts of infection in the reproduction. Spread from bole infections is generally minor (Walters 1974).

The proportion of the total number of young infected trees within various distances of the mature stand is shown in figure 8. Sixty-four percent of the infected trees were within 20 feet (6 m) of the residual stand, 89% within 30 feet (9 m), and 98% within 40 feet (12 m).

Long-Distance Spread

Very little is known about long-distance dispersal of *A. americanum* seed. The frequent occurrence of isolated pockets of infection beyond the limits of spread that could be accounted for by the explosive fruits alone confirms that there is some long-distance spread. The only study to quantify long-distance spread in *A. americanum* is by Hawksworth et al. (1987) on the Fraser Experimental Forest in Colorado. They surveyed for isolated, satellite infection centers in an otherwise mistletoe-free 70-year-old stand surrounded by heavily infested stands. They found 21 satellite centers in a 37-acre stand, or 0.6 per acre (1.4 per ha). The centers ranged from 39 to 213 feet (12 to 65 m) from the closest potential infection source. Ages of infection in the centers ranged from 4 to 50 years, but most were 10 to 20 years old. More than two-thirds of the satellite centers were near openings in the stands, probably because such areas are a more attractive habitat for birds, which are presumed to be responsible for long-distance dispersal of mistletoe seeds.

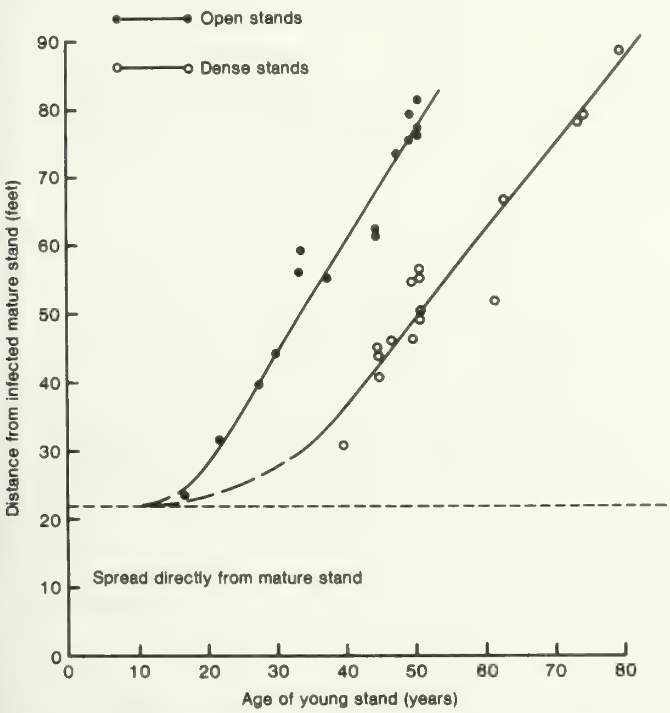


Figure 6.—Lateral spread of dwarf mistletoe from mature lodgepole pine stands into regeneration; based on 31 study areas in Colorado and Wyoming (Hawksworth 1958a).

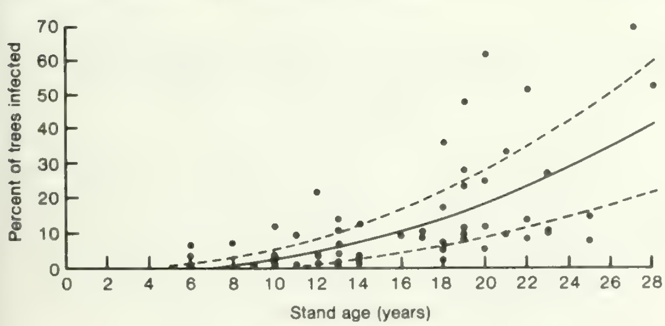


Figure 7.—Percent of young lodgepole pines infected within 30 feet (9 m) of infested residual stands on 79 plots in Colorado, Wyoming, and Montana. The dotted lines indicate 95% confidence intervals (Hawksworth and Graham 1963).

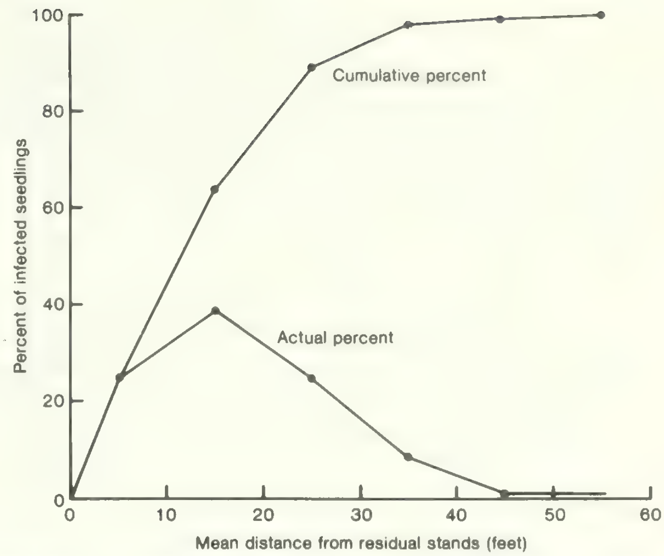


Figure 8.—Distance of infection in young lodgepole pine stands in relation to residual stands. Based on 325 infected trees in stands in Colorado, Wyoming, and Montana (Hawksworth and Graham 1963).

Hawksworth et al. (1987) and Nicholls et al. (1984) studied the potential animal vectors of lodgepole pine dwarf mistletoe on the same area on the Fraser Experimental Forest. They found dwarf mistletoe seeds being carried externally by 10 species of birds and four mammals (Plate IV). About 7% of the birds and mammals trapped carried mistletoe seeds, but this was as high as 22% during the 2-week period of peak seed dispersal.

Intensification

Muir (1972) studied rates of intensification of *A. americanum* in young lodgepole pines in Alberta. In lodgepole pine from 15 to 26 years old, the number of dwarf mistletoe plants increased exponentially. During this 9-year period, the number of infections increased about four times every 5 years.

Hawksworth and Hinds (1964) studied even-aged lodgepole pine in Colorado and found that the average stand dwarf mistletoe rating (DMR) increased an average of about one DMR class in 14 years in stands 15 to 60 years old (fig. 9). The rate was somewhat slower in stands under 15 and those over 60 years old.

Biotic Associates

There are many biological associates of lodgepole pine dwarf mistletoe (Plate IV). Several fungi parasitize the shoots, fruits, and endophytic system; insects, mammals, and birds feed on the shoots; and the witches' brooms provide cover and nest sites for birds and squirrels (Hawksworth 1975).

Fungi

Cylindrocarpon (Septogloeum) gillii (Ellis) Muir is an occasional parasite of *A. americanum* in the United States and Canada (Hawksworth et al. 1977). *Wallrothiella arceuthobii* (Peck) Sacc. parasitizes mistletoe fruits and prevents seed formation. Although both fungi have some local influence on mistletoe populations, their overall effect is minor. Two other disease syndromes involving pine tissue and lodgepole pine dwarf mistletoe have been studied, but their potential as significant biological control agents has not been demonstrated: the "resin disease," caused by a complex of weakly parasitic fungal pathogens (Mark et al. 1976) and the blister rust fungus *Peridermium bethelii* (Hawksworth et al. 1983).

Insects

At least 10 species of insects feed on lodgepole pine dwarf mistletoe (Stevens and Hawksworth 1970, 1984). The most damaging are lepidoptera larvae; others that attack dwarf mistletoe shoots are plant bugs of the genus *Neoborella*. Neither the extent of the damage they cause nor their biological control potential have been determined. In some instances, birds forage for insects in clumps of dwarf mistletoe shoots and, thus, when fruits are ripe, may pick up and transport mistletoe seeds (see next section).

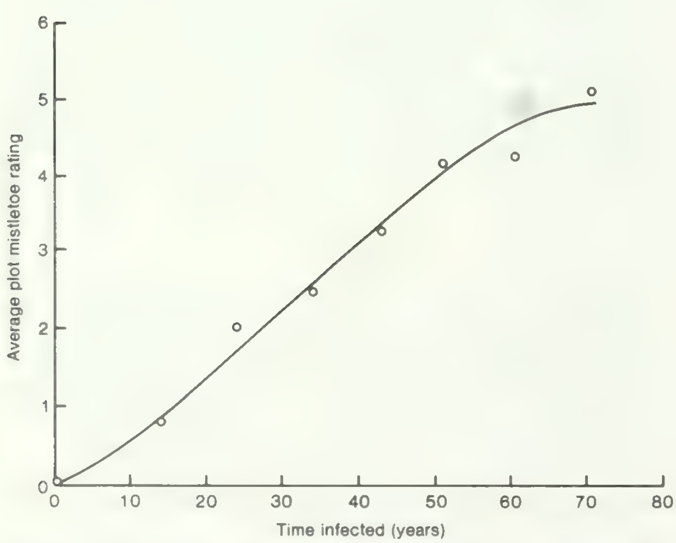


Figure 9.—Relationship between the time infected and stand dwarf mistletoe rating in lodgepole pine in Colorado. Based on 126 plots in stands 50 to 150 years old (from Hawksworth and Hinds 1964).

Birds and Mammals

Some birds (ruffed grouse, blue grouse, black-capped chickadee) are reported to eat dwarf mistletoe seeds (Hawksworth 1975), and red squirrels (*Tamiascuirus hudsonicus*) preferentially eat mistletoe-infected rather than healthy bark (Baranyay 1968). Craighead et al. (1973) note an unusual instance where dwarf mistletoe plants, which are rich in protein, are a major winter food for elk in the thermal areas of Yellowstone National Park, Wyoming.

ECOLOGY

Because of the intimate association of dwarf mistletoe with its lodgepole pine host, the ecological factors that affect the host also directly influence the parasite. Little information is available on the ecological interrelationships of dwarf mistletoes, but the limited research indicates that ecological factors are very important in mistletoe distribution and abundance. Some factors that have been studied are (1) plant associations or habitat types, (2) topography, (3) site factors, and (4) stand fire history.

Plant Associations

The first report of the association of vegetative types with a dwarf mistletoe was Dowding's (1929) study of *A. americanum* on *Pinus banksiana* in central Alberta. She showed that the parasite was much more common in the drier pine-moss association (71% of trees infected) than in the moister pine-heath association (5% of trees infected). Fuller and Hostetler (1980) found marked differences between understory vegetation in lodgepole pine and frequency and abundance of dwarf mistletoe (table 3). Unfortunately, when that study was made, habitat type classifications had not been completed for the lodgepole pine forests in Colorado.

The use of the habitat type classification system of vegetation has increased greatly in the past decade in the Rocky Mountains. A habitat type is usually defined as a unit of land capable of producing a certain plant community at climax (Daubenmire and Daubenmire

Table 3.—Frequency and average mistletoe rating for lodgepole pine dwarf mistletoe by understory vegetation; based on 277 plots from Colorado (from Fuller and Hostetler 1980).

Predominant understory vegetation	No. of plots	% of plots with dwarf mistletoe	Average mistletoe rating
Shepherdia canadensis	12	50	1.3
Vaccinium scoparium	90	30	1.1
Juniperus communis	31	35	1.1
Arctostaphylos uva-ursi	41	23	1.0
Arnica cordifolia	12	33	1.0
Grasses (no shrubs)	45	20	0.7

1968). Although a given habitat type may support several seral plant communities, the final stage of plant succession will be a specific climax community. Thus, the habitat type system uses climax plant communities as an integrating indicator of the environmental conditions that influence plant reproduction, competition, and community development (Steele et al. 1981). The earliest study to compare lodgepole pine dwarf mistletoe in various habitat types was by Roe and Amman (1970), who examined 42 stands in the three main lodgepole pine habitat types in western Wyoming (Yellowstone and Teton National Parks, Bridger and Teton National Forests) and southeastern Idaho (Targhee National Forest):

Habitat type	Mean stand dwarf mistletoe intensity[2]
Abies lasiocarpa/Vaccinium scoparium	2.5
Abies lasiocarpa/Pachystima myrsinites	1.9
Pseudotsuga menziesii/Calamagrostis rubescens	1.6

A much more refined habitat type classification system for this area has since been developed by Steele et al. (1983). The habitat types cited by Roe and Amman (1970) are so broad that they cannot be correlated directly with the habitat type classes under the revised system. However, the *Pseudotsuga menziesii/Calamagrostis rubescens* habitat type, which had the least infection, probably has the lowest lodgepole pine growth potential of the three habitat types examined (R. Steele, personal communication, 1985).

Mauk and Henderson (1984), who developed a habitat type classification for northern Utah, included an evaluation of dwarf mistletoe for lodgepole pine in the Uinta Mountains. They recognized 26 habitat types that support lodgepole pine, 10 of which had dwarf mistletoe. The four types where infection was highest were: *Pinus contorta/Arctostaphylos uva-ursi* habitat type; *Abies lasiocarpa/Vaccinium scoparium* habitat type, *Carex geyeri* and *Vaccinium scoparium* phases; and the *Pinus contorta/Vaccinium caespitosum* community type (c.t.). The four types with heavy infection had a slightly lower average lodgepole pine site index [36 feet (11 m) at age 50] than the mistletoe-free types [39 feet (12 m) at age 50], but the data were so variable that the differences were not significant.

Wirsing (1973) studied habitat types in the Medicine Bow National Forest in southeastern Wyoming and found that dwarf mistletoe in lodgepole pine was more common in the *Pinus contorta/Carex geyeri* c.t. than in the more mesic *Pinus contorta/Vaccinium scoparium* c.t. Oswald (1966) noted that dwarf mistletoe was abundant in all four lodgepole pine communities recognized in the forested moraines of the valley floor in Grand Teton National Park, Wyoming.

No quantitative studies on the effects of dwarf mistletoe in various lodgepole pine habitat types and community types have been made. However, observations suggest that there are marked differences, such as have been documented for other host/parasite combinations. For example, the effects of heavy infection [dwarf mistletoe infection classes 5–6 (Hawksworth 1977)] by Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) on 10-year radial growth increment in the Southwest ranged from 24% to 75% in different habitat types (Mathiasen and Blake 1984).

Such studies are urgently needed for lodgepole pine in the Rocky Mountains. However, caution is advised in attempting to relate mistletoe occurrence to habitat types because of many other factors that may affect mistletoe distribution and abundance, especially past management practices, fire history, stage of succession, and topography.

[2] Based on a 4-class rating system: 1 = no dwarf mistletoe, 2 = less than one-third of trees infected, 3 = one-third to two-thirds of trees infected, and 4 = more than two-thirds of trees infected.

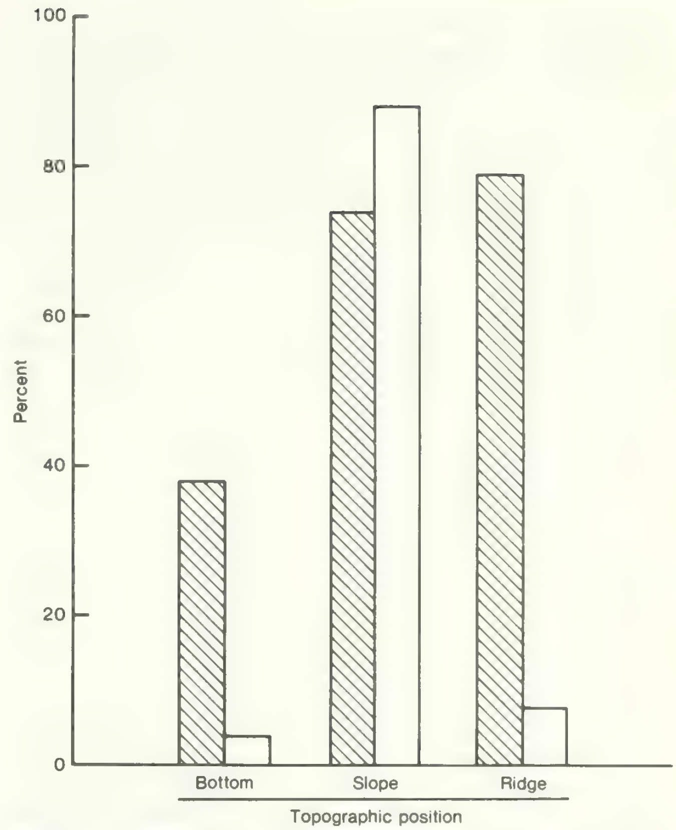


Figure 10.—Distribution of lodgepole pine dwarf mistletoe in relation to topographic position. Solid bars show incidence of dwarf mistletoe in each position. Open bars show distribution of plots in the three positions. Based on 426 plots in Colorado and Wyoming (Hawksworth 1958a).

Topography

Little information is available on the relationship of topography and lodgepole pine dwarf mistletoe.

Arceuthobium americanum is typically most abundant on ridges, but ridge sites occupy a relatively small proportion of the lodgepole pine area. Figure 10 shows the frequency of *A. americanum* in 426 lodgepole pine plots in the Roosevelt National Forest, Colorado, and the Medicine Bow and Bighorn National Forests in Wyo-

ming. No studies have been reported on the relationships of lodgepole pine dwarf mistletoe and steepness of slope or aspect.

Elevation is the one physical site factor for which a considerable amount of information is available for lodgepole pine dwarf mistletoe (Hawksworth 1956, Williams et al. 1972). *A. americanum* ranges from as low as 700 feet (215 m) in northern Alberta to as high as 11,000 feet (3,350 m) in central Colorado. Hawksworth (1956) showed that there was a mistletoe-free zone of about 500 feet (150 m) in elevation just below the upper limits of the commercial lodgepole pine zone in the Rocky Mountains. The upper limits of *A. americanum* are about 9,000 feet (2,740 m) in northern Wyoming, and 10,000 feet (3,050 m) in northern Colorado (fig. 11).

Hawksworth and J. G. Laut (unpublished data, 1986) studied the reasons for the mistletoe-free zone in northern Colorado by transplanting mistletoe-infected lodgepole pines into the zone. After nearly 20 years, the mistletoe plants survived vegetatively and flowered, but fruits did not mature. The growing season at this elevation is apparently not long enough for the fruits to mature before the killing frosts in the autumn.

In a laboratory study, Baranyay and Smith (1974) found that *A. americanum* fruits exposed to 3.9° C for 2 to 5 hours were permanently damaged, and no seed dispersal occurred. Becwar et al. (1982) studied the cold-hardiness of dwarf mistletoe shoots and seeds, including *A. americanum*. Lodgepole pine dwarf mistletoe seeds avoided freezing damage by deep undercooling to about −35° C. Seeds cooled to −40° C were killed; however, vegetative shoots of this mistletoe survived cooling to −70° C.

Site Factors

No studies have been made to correlate incidence or abundance of lodgepole pine dwarf mistletoe with site quality in the Rocky Mountains. However, Hadfield (1977) found no direct relationship between site and dwarf mistletoe frequency in eastern Oregon or eastern Washington; dwarf mistletoe was most frequent in sites 65 to 75 feet, and least in stands over site 85 (height at base age 100 years).

Site index (feet)	Frequency of dwarf mistletoe (%)
<65	35
65–75	51
75–85	33
>85	20

Hawksworth and Graham (1963) measured the amount of mistletoes in young lodgepole pines adjacent to an infected overstory in the central and northern Rocky Mountains. They found a marked relationship between the abundance of dwarf mistletoe and height of the dominant trees in the young stand. Stands were classed as above or below average based on height of dominant trees: 6 feet (1.8 m) for stands 5–12 years old, 8 feet (2.4 m) for stands 13–19 years old, and 12 feet (3.7 m) for stands 20–28 years old. The percentage of trees infected, with mean and standard errors, were:

Tree height and age class	No. plots	% of trees infected
Above average:		
5–12 years	9	3.5 ± 2.5
13–19 years	12	14.5 ± 4.2
20–28 years	6	45.0 ± 10.4
Below average:		
5–12 years	15	0.4 ± 0.3
13–19 years	12	6.7 ± 1.8
20–28 years	6	9.7 ± 1.1

For reproduction at a given age, the proportion of trees infected was significantly higher for the plots with the tallest trees. Also, within a stand of reproduction, the tallest trees were usually infected first, presumably because they present more exposed target area. The percentage of plots with dwarf mistletoe was greater on the plots with above-average height growth, particularly in the younger stands. In the 5- to 12-year age class, the parasite occurred on 67% of the above-average plots, but on only 27% of the below-average plots. Thus, the evidence is strong that reproduction on good sites adjacent to an infected overstory is more prone to infection.

Our observations indicate that dwarf mistletoe occurs on essentially all sites in the central and northern Rocky Mountains (site indices at base age 100 from <30 to >95 feet (<9 to >29 m), although volume loss attributed to the parasite is less on better sites. Additional studies are needed to quantify the relationship of site factors to incidence and severity of lodgepole pine dwarf mistletoe.

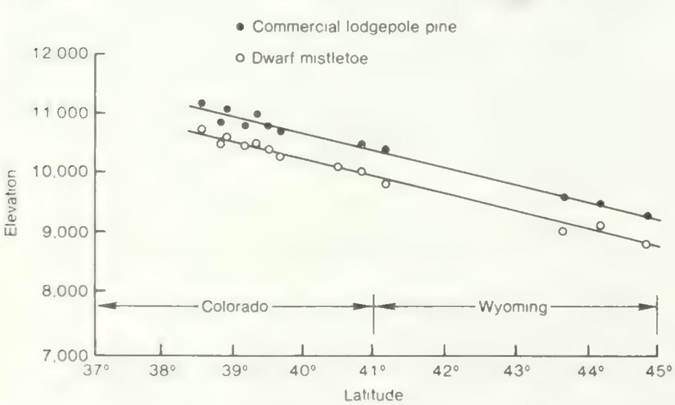


Figure 11.—The upper altitudinal limits of commercial lodgepole pine and dwarf mistletoe from central Colorado to northern Wyoming. The mistletoe-free zone averages about 500 feet in height. Updated from Hawksworth (1956).

Fire History

Wildfires have been most important in determining the present distribution of lodgepole pine dwarf mistletoe, because fire is the only effective natural control agent (Alexander and Hawksworth 1975, 1976, 1986). Little is known on the direct effects of smoke on dwarf mistle-

toes, but Zimmerman and Laven (1987) found that exposure of lodgepole pine dwarf mistletoe seeds to forest-fuel smoke for 60 minutes or longer inhibited germination but that exposure up to 30 minutes slightly increased germination.

Fire is particularly important for this dwarf mistletoe, because the development of most lodgepole pine forests has been fire-dependent. The many interrelated factors that influence fire cycles in lodgepole pine are summarized by J. K. Brown (1975). These include fuel build-up, mountain pine beetle epidemics, and dwarf mistletoe effects (fig. 12). Fire has played a major role in the determination of the present mistletoe distribution patterns of lodgepole pine and its mistletoe. For example, Baranyay (1972) stated that dissimilarities in fire history are the primary reason why there is much more dwarf mistletoe in lodgepole pine in the upper foothills and east slope Rockies forest types than in the lower foothills of Alberta. In the lower foothills, wildfires during the past 100 years were very extensive and complete. The young lodgepole pine stands that developed in these burns are relatively free of mistletoe. In the other two forest types, however, variations in topographic and forest conditions prevented the development of large conflagrations. Many residual mistletoe-infected trees survived and infected the young stands that developed after wildfires.

Surveys by Hawksworth (1958a) show that dwarf mistletoe is considerably less in regenerated burns than in adjacent virgin or cut-over stands:

Stand condition	Percent of stands Infested	Heavily infested
Virgin	49	28
Partially cut	66	41
Regenerated burns	24	5

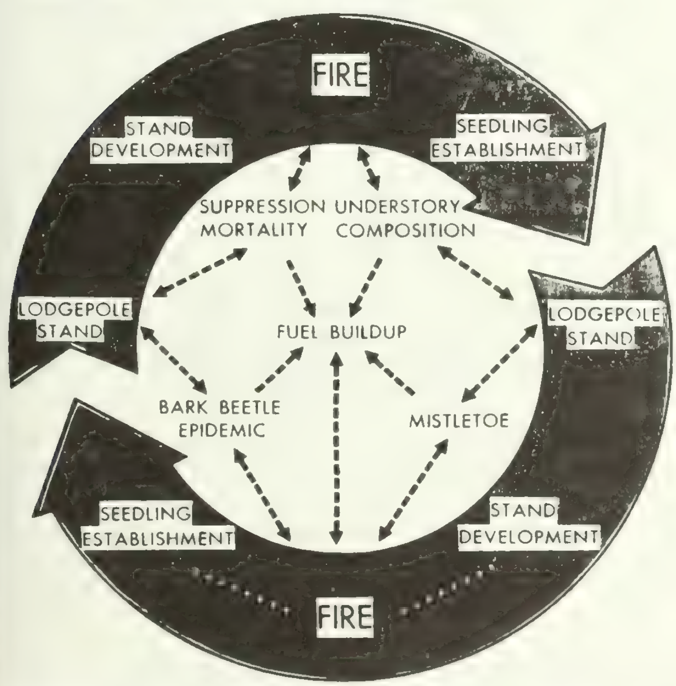


Figure 12.—The many related factors influencing the fire cycle in lodgepole pine forests (from J. K. Brown 1975).

Lodgepole pine reproduction in clearcuts or burned areas in the northern Rocky Mountains of Idaho and Montana is generally uninfected or only lightly infected by dwarf mistletoe (LeBarron 1952). Lotan (1975) stated that fire provides a self-correcting check on insects and diseases, and noted the lodgepole pine area burned by the large Sleeping Child fire in Montana is likely to be relatively free of mountain pine beetle (*Dendroctonus ponderosae*) and dwarf mistletoe for decades. Similarly, Taylor (1969) found that infection in regenerated lodgepole pine burns in Yellowstone National Park was relatively low. The slow reinvasion of dwarf mistletoe from adjacent unburned stands was correlated with time since the burn.

Years since burn	% of lodgepole pines infected
7	0
13	0
25	0
57	1
111	10
ca. 300	36

Lodgepole pine dwarf mistletoe usually is more common on ridge and slope sites than in bottom sites (Hawksworth 1958a). This may be, at least partly, a result of different intensities of wildfires and tree survival at the different sites, because ridge stands tend to be more open with less fuels.

Immature lodgepole pine stands infested by dwarf mistletoe have more dead material on the ground, more stems, and more foliage near the ground than comparable uninfested stands (Alexander 1979, Hawksworth and Hinds 1964). J. K. Brown (1975) stated that dwarf mistletoe often adds to the ground fuel, and also that witches' brooms enhance vertical fuel continuity and, thus, increase the likelihood of ground fuels creating a "fire ladder" to burn individual tree crowns. The witches' brooms also tend to trap fallen needles, thus increasing the vertical scattering of fine fuels which are ideally situated for optimal flammability.

In a broad, ecological sense, wildfires may tend to increase certain mistletoe-susceptible seral tree species, such as lodgepole pine and jack pine. For example, the climax spruce-fir (*Picea engelmannii-Abies lasiocarpa*) forests of the Rocky Mountains are generally resistant to dwarf mistletoes; the seral lodgepole pine, which frequently replaces spruce-fir on burned sites, is very susceptible to dwarf mistletoe (Kuijt 1955, Hawksworth 1975). Whether or not mistletoe increases in the seral stand, however, depends on the availability of infection sources. If no infected lodgepole pines occur in the area, then young lodgepole pine stands will remain free of dwarf mistletoe. An important role of fire in relation to succession seems to be the maintenance of seral stands by intermittent fire. Dwarf mistletoe seed sources are not eliminated; therefore, the disease is maintained in subsequent seral stands.

Control of wildfires over the past few decades may have increased the amount of dwarf mistletoe in lodge-

pole pine forests (Alexander and Hawksworth 1975). Zimmerman and Laven (1984) quantified this in one area in central Colorado and showed the fire frequency peaked between 1860 and 1890 (long before fire control efforts were initiated) and has declined steadily since then. Concurrently, dwarf mistletoe increased from very low levels before 1900 to where essentially every stand is infested to some degree today.

HOST EFFECTS

Dwarf mistletoes affect their hosts in several ways, some of which have not been quantified. Heavily infected trees show a marked decline in vigor, as evidenced by upper crowns that are more open and have smaller, yellow-green needles. The rates of height and diameter growth decline, seed and cone production is reduced, and eventually trees start to die back from their tops. Premature death follows, usually aided by secondary bark beetles.

Vigor

Hawksworth (1958a) quantified the relationship of dwarf mistletoe to vigor of lodgepole pine. He compared the board foot volume in infected and uninfected trees in the four vigor classes as defined by Taylor (1939) (fig. 13):

Class A.—Crown area: 30% or more of the "extreme maximum" outline of vigor class A. Crown length: 50% or more of the bole length. Crown vigor: dense, full, of good color, and pointed.

Class B.—Crown area: usually more than 30% but less than 50% of the "extreme maximum" outline of vigor class A. Crown length: usually more than 50% but less than 60% of the bole length. Crown vigor: moderately dense, of good color, pointed, or slightly rounded.

Class C.—Crown area: 17% to 30% of the "extreme maximum" outline of vigor class A. Crown length: 40% to 50% of the bole length except for trees with distinctly better than average vigor when a minimum of 20% of the bole length is sufficient. Crown vigor: sparse, bunchy, color poor, never pointed.

Class D.—All live trees of poorer vigor than class C. Includes trees with class A, B, or C outlines but with dying or multiple tops.

A summary of the percentage of tree volume in each dwarf mistletoe or vigor class in virgin and cutover stands is given in figure 14. Volume in trees of highest vigor (class A) was much greater in uninfected than infected trees in both stand types. Thirty-three percent of the volume was in infected trees in the better vigor classes (A and B) compared to 56% for uninfected trees in virgin stands.

A more detailed analysis from the data collected by Hawksworth (1958a) was made to determine the relationship between vigor rating and dwarf mistletoe intensi-

Figure 13.—Lodgepole pine tree vigor classes (Taylor 1939).

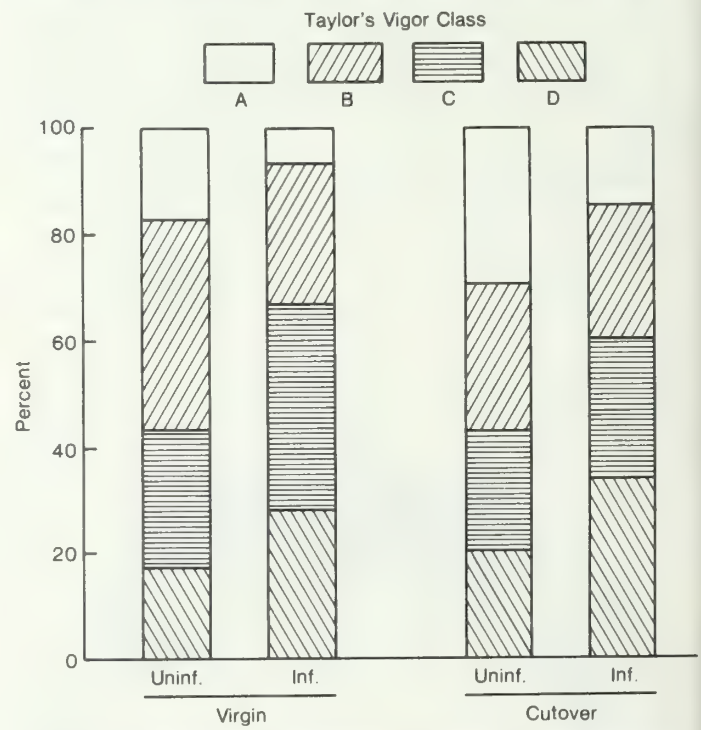


Figure 14.—Distribution of board-foot volume in 2,610 trees by Taylor vigor class for uninfected (uninf.) and infected (inf.) lodgepole pines (>10 inches d.b.h.) in virgin and cutover stands in Colorado and Wyoming (Hawksworth 1958a).

ty. The results (fig. 15) show that trees with higher mistletoe intensities have lower vigor ratings. For example, about 20% of the trees in infection classes DMR 0–2 were in vigor class A. This dropped to 15%, 9%, 3%, and 0% for trees in infection classes 3, 4, 5, and 6, respectively. Similarly, trees of the poorest vigor (class D) averaged about 20% for trees in infection classes 0–3, but this increased for trees in infection classes 4, 5, and 6 to 26%, 28%, and 66%, respectively.

Schaffer et al. (1983a) used a Shigometer to measure the electrical resistance of lodgepole pines of various

dwarf mistletoe intensities (6-class system) and vigor classes. Vigor was subjectively rated into three classes:

Good: normally colored foliage, full crown.
Fair: foliage color or crown density intermediate.
Poor: off-color foliage or open crown.

Electrical resistance was significantly related to vigor class (good: 16.3 ± 0.4 k-ohms; fair: 21.9 ± 1.2 k-ohms; and poor: 30.0 ± 3.6 k-ohms). Only the most heavily infected trees (class 6) had a significantly higher electrical resistance than the healthy or less severely infected trees.

Diameter Growth

Hawksworth and Hinds (1964) determined the effects of dwarf mistletoe on diameter growth on 25 even-aged plots in Colorado that ranged from 50 to 150 years old. Reduction in diameter growth was significantly correlated to time since infection: for the first 70 years after infection, reduction in diameter growth averaged about 5% per decade. That is, trees that had been infested for 70 years showed a radial growth of about 65% of that of comparable uninfected trees (fig. 16).

Baranyay and Safranyik (1970) conducted the only tree-dissection study to determine growth rates of mistletoe-infected lodgepole pines. They dissected five trees in Alberta: two healthy, one lightly infected, and two heavily infected (classes 2 and 3).[3] Trees were measured at stump height (1 foot) and at 8-foot intervals to the top. Radial growth in lightly infected trees was not significantly different than the uninfected trees, but the two

[3]Based on a 4-class rating system: 0 = healthy; 1 = light branch infections, less than 50% of the crown infected; 2 = heavy branch and stem infections, more than 50% of the crown infected; and 3 = witches' brooms, branch and stem infections, more than 50% of the crown infected.

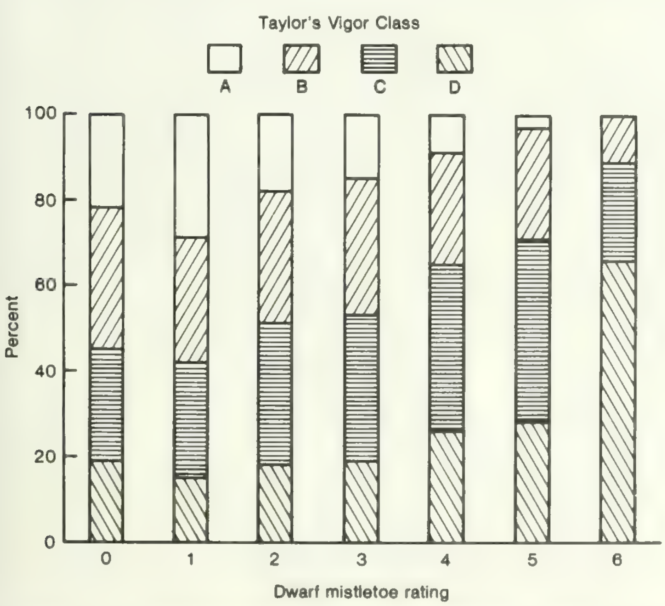


Figure 15.—Relationship between dwarf mistletoe intensity and Taylor vigor class. Based on 2,610 mature trees (>10 inches d.b.h.) in Colorado and Wyoming. Data from survey reported by Hawksworth (1958a).

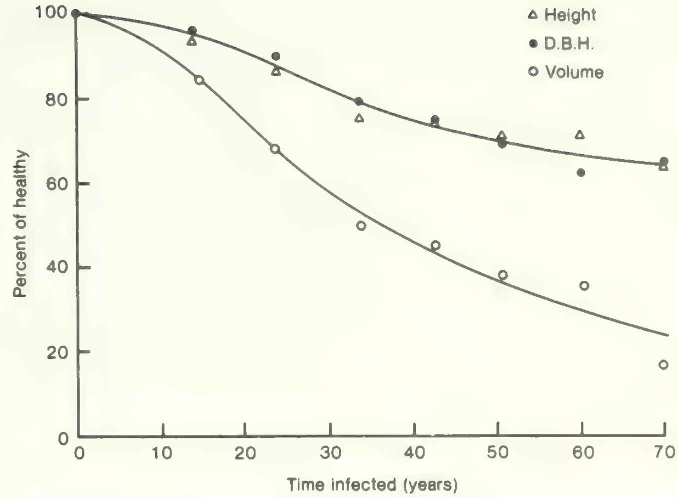


Figure 16.—Relative height, d.b.h., and cubic foot volume of dominant and codominant lodgepole pines in relation to time since infection. Based on 133 plot pairs on 25 transects in Colorado (Hawksworth and Hinds 1964).

heavily infected trees had significantly ($P = 0.01$) slower growth rates. Although Baranyay and Safranyik (1970) did not summarize their data on radial growth reduction in relation to tree height, their diagrams suggest that the effects of mistletoe are slightly more pronounced with increasing height above the ground.

Data from more than 3,000 trees in 25 even-aged plots in Colorado (Hawksworth and Hinds 1964) were analyzed for radial growth rate at d.b.h. in comparison with dwarf mistletoe intensity, crown class, and stand density (table 4). The radial growth rate in dominant trees decreased markedly in heavily infected (classes 5 and 6) trees. Growth in class 5 and 6 trees was 75% and 54%, respectively, of that in class 0–3 trees in open stands compared to 90% and 76% for dense stands, respectively. The relative effects of dwarf mistletoe were more pronounced in open than in dense stands; growth rates of class 4 trees were less in open stands (89%) than in dense ones (96%). In open stands, the percentage losses were similar in dominant, codominant, and intermediate, but less in suppressed trees. However, in dense stands, losses were most marked in codominant and intermediate trees, less so in suppressed, and least in dominant trees. For all 3,015 trees analyzed, growth reduction in relation to that in classes 0–3 by dwarf mistletoe intensity was:

Class 4	6%
Class 5	20%
Class 6	41%

A general equation for estimating the difference in 10-year radial growth in even-aged lodgepole pine stands (Myers et al. 1971) is:

$$Y = 1.0222\,X_1 + 0.0151X_2 - 1.2417\,\log^{10} X_3 + 2.1450$$

where

Y = 10-year radial growth difference from healthy stands,
X_1 = d.b.h. at start of period,
X_2 = site index (feet at base age 100), and
X_3 = basal area (square feet) per acre.

Table 4.—Ten-year radial growth rates in open (<1000 trees/acre) and dense (>1000 trees/acre) stands in relation to dwarf mistletoe intensity and crown class; based on 25 even-aged plots in Colorado and Wyoming.

Density	Crown class	No. of trees	Growth (in.) for DMR class 0–3	10-yr radial growth rate expressed as a percentage of class 0–3 for DMR class		
				4	5	6
Open	Dominant	132	0.35	89	75	54
	Codominant	106	0.29	100	83	52
	Intermediate	659	0.25	99	90	52
	Suppressed	217	0.14	92	82	65
Total and unweighted means		1,114	0.26	95	82	56
Dense	Dominant	179	0.21	96	90	76
	Codominant	206	0.20	67	63	52
	Intermediate	605	0.14	101	84	56
	Suppressed	911	0.06	109	77	60
Total and unweighted means		1,901	0.15	93	78	61

For stands with an average stand dwarf mistletoe rating of less than 3.9, no adjustment is needed.

In summary, low intensities of dwarf mistletoe have no measurable effect on radial growth. As a rule, the threshold level for growth reduction seems to be class 3, or when about one-half of the crown becomes infected. In some instances (e.g., for intermediate or suppressed trees in dense stands), growth loss may be detected only in class 5 and 6 trees.

Effects of dwarf mistletoe on average stand diameter for lodgepole pine stands of various intensities of infection using the RMYLD program were determined by Van der Kamp and Hawksworth (1985). For this analysis, a site index of 60 feet (18.3 m), thinning interval of 20 years, and growing stock level (GSL) of 100 ft^2/acre (23 m^2/ha) were used. GSL is defined as the residual square feet of basal area where average stand diameter is 10.0 inches or more (Alexander and Edminster 1980). As shown in figure 17, infection class DMR 1 has no measurable effect, but higher ratings have progressively more effect so that, by class DMR 5, decreases in growth were significant.

Height Growth

Despite all the research on lodgepole pine dwarf mistletoe, relatively little quantitative data are available on the effects of the parasite on height growth of the host. Weir (1916) measured 50 infected and 50 uninfected 60- to 65-year-old lodgepole pines in northern Idaho and eastern Washington. Uninfected trees averaged 48.5 feet (14.8 m) high, compared to 35.2 feet (10.7 m) for infected trees, a difference of 27%.

Dwarf mistletoes generally have more effect on height growth than on diameter growth. However, Hawksworth and Hinds (1964) (see previous section), in a study of 25 even-aged lodgepole pine stands in Colorado and Wyoming, found that growth retardation in height and diameter were about the same (i.e., about 0.5% per year).[4]

Baranyay and Safranyik (1970) found no effect of light infection on height growth in Alberta. However, heavily infected trees were slightly shorter in a dry, but not on a wet, site.

Meyers et al. (1971) developed the following relationship between 10-year reduction in height growth in

[4]*Erroneously reported by Hawksworth and Hinds (1964) as 0.7% per year.*

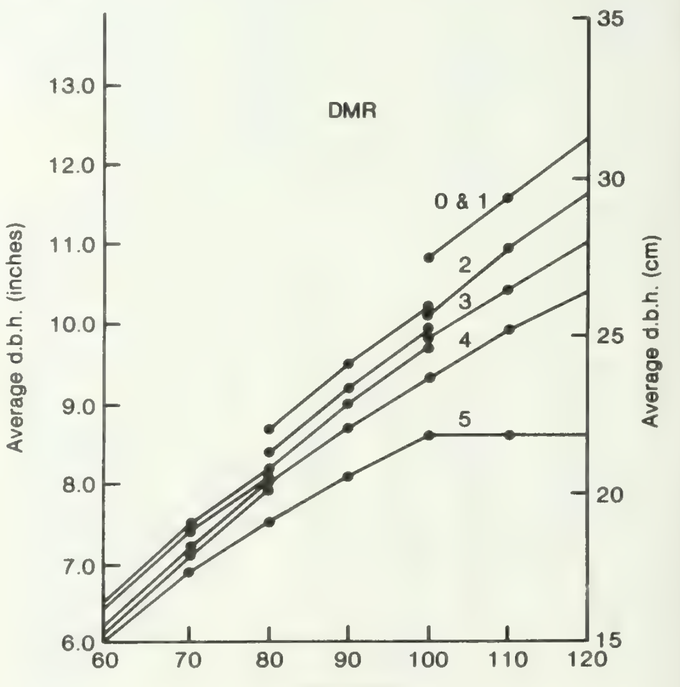


Figure 17.—Relationship between diameter growth and dwarf mistletoe rating (DMR). Mistletoe ratings at age 60. Site index 60 feet (18.3 m), thinning interval 20 years, and growing stock level 100 ft^2/acre (23 m^2/ha.)

dominant and codominant trees, and stand dwarf mistletoe rating [based on the data of Hawksworth and Hinds (1964) from 25 stands in Colorado]:

$$\hat{Y} = 100 - 1.65\, X_1^{3}$$

where

$\hat{Y}$ = percent reduction in height growth compared to mistletoe-free trees, and
X_1 = dwarf mistletoe rating.

This is equivalent to:

DMR	10-year percent height growth reduction
0–1	0
2	2
3	8
4	18
5	35
6	60

Mortality

There is considerable literature on the deleterious effects of lodgepole pine dwarf mistletoe on yields, but most studies do not separate losses resulting from growth reduction from those caused by mortality.

Hawksworth (1958a) compared mortality in mistletoe-free stands and those with various intensities of dwarf mistletoe in Colorado and Wyoming. Recent mortality was greater in infested than in uninfested stands. To compare infested and uninfested stands, recent mortality was calculated as the volume of standing dead trees with bark intact[5] expressed as a percentage of the gross volume in both living and dead trees. Recent mortality in uninfested virgin stands was 800 board feet per acre, while that in infested stands was 1,020 board feet, or 1.3 times, greater (table 5). The difference between percent mortality in infested and uninfested stands is greater than 1.3, since past mortality and growth reduction caused by the parasite lowered the gross volume in infested areas. Mortality in cutover stands was 490 board feet per acre (8.8% of gross volume) in uninfested plots and 560 board feet (12.5% of gross volume) in plots with dwarf mistletoe.

[5]*This approximates mortality during the previous 10 years.*

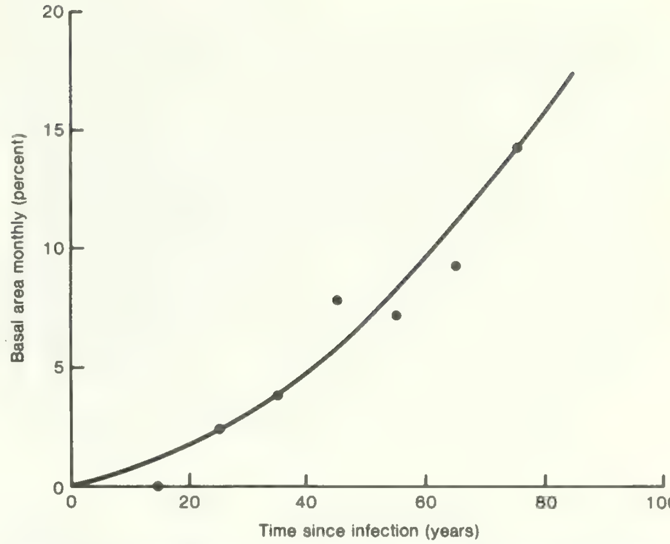


Figure 18.—Basal area mortality for previous 10 years in infested stands in relation to uninfested stands. Data from 25 even-aged stands in Colorado (Hawksworth and Hinds 1964).

Hawksworth (1958a) found that stand density in uninfested pole stands was about 1.5 times that in infested stands. In large poles (those over 5.6 inches d.b.h.), mortality in infested stands was five times greater than in mistletoe-free stands. However, in small poles where suppression is the predominant mortality factor, the proportion of dead trees in infested and uninfested stands was about the same.

In a study of 25 even-aged lodgepole pine stands in Colorado and Wyoming, Hawksworth and Hinds (1964) found that mortality was directly related to time since dwarf mistletoe infection began (fig. 18). Basal area in dead, standing trees as a percentage of total basal area in living plus dead trees increases dramatically with time since infection from less than 5% for stands infested for about 40 years to 15% in stands infested for 80 years.

Baranyay and Safranyik (1970) studied five infested lodgepole pine stands in Alberta and found that recent

Table 5.—Effect of dwarf mistletoe on volume and recent mortality in merchantable lodgepole pine in virgin stands, based on 151 plots in Colorado and Wyoming (Hawksworth 1958a).

Stand type	Plot basis	Gross volume per acre			Mortality[1]
		Living	Dead	Total	
	no.	---------	*board-feet*	---------	%
Not infected	44	10,930	800	11,730	6.8
Infected:					
Light (DMR 1-2)	23	10,100	1,180	11,280	10.5
Moderate (DMR 3-4)	36	7,990	1,150	9,140	12.6
Heavy (DMR 5-6)	48	5,280	850	6,130	13.8
Total or average	107	7,230	1,020	8,250	12.4

[1]*Dead standing trees with bark intact—approximate mortality during previous 10 years.*

mortality (dead standing trees with bark intact) was related to time since infection and was higher on dry than on wet sites (table 6).

General equations for estimating 10-year mortality in even-aged lodgepole pine stands in the central Rocky Mountains are given by Myers et al. (1971). For stands with less than 1,000 stems/acre:

$$\hat{Y} = -0.663 + .0381\ X$$

for stands with greater than 1,000 stems/acre,

$$\hat{Y} = -0.864 + .0328\ X$$

where

$\hat{Y}$ = percent tree mortality in 10 years, and
X = stand DMR.

These equations apply only to stands with an average DMR of 3.9 or more; below that level, mistletoe-caused mortality is negligible.

Volume Growth

Because of reduced rates of height and diameter growth in infected trees and increased rates of mortality, volume growth in infested stands is typically less than in comparable mistletoe-free stands. The actual reduction depends on several factors, primarily intensity of infection, site index, and stand density.

To enable forest managers to predict yields in healthy and mistletoe infested stands, the RMYLD simulation program was developed for lodgepole pine for the central Rocky Mountains by Edminster (1978). This program makes it possible to estimate yields in infested stands with various stand management alternatives (thinning intensity, thinning intervals, rotation ages) (appendix I).

The only other lodgepole pine growth and yield model that considers dwarf mistletoes is Schmitt and Wittala's (1983) modification of Dahm's (1983) yield tables for central Oregon.

A comparison of estimated yields (using the RMYLD system) in lodgepole pine of three growing stock levels (GSL) 60, 100, and 140 ft^2/acre (13.8, 23.0, and 32.1 m^2/ha) and various intensities of DMR's appear in table 7 (Van der Kamp and Hawksworth 1985). Intensity of infection is based on the 6-class (DMR) rating system (Hawksworth 1977). For the comparisons, these conditions are assumed: present age, 60 years; 600 trees/acre (1,483 trees/ha); site index, 60 feet (18.3 m); average d.b.h., 6.0 inches (15.2 cm); thinning interval, 20 years. Projections are made for a 60-year period on to rotation age 120. Results show that, for healthy and lightly infested stands (up to DMR 2), anticipated yields increase with growing stock levels. For stands with a DMR 3 or 4 at the beginning of the period, there is little relationship between GSL and yields, and for heavily infested (class 5) stands, yields decrease with increasing GSL. For example, in DMR class 5 stands with a GSL of 60 ft^2, an-

Table 6.—Mortality in five lodgepole pine stands in Alberta in relation to stand factors and dwarf mistletoe (adapted from Baranyay and Safranyik 1970).

Stand	Stand age	Time infected	Trees infected	Mortality due to mistletoe[1]
	yr	yr	%	%
Dry site 1	37	28	48	0
Dry site 2	59	41	77	11
Dry site 3	86	45	58	10
Dry site 4	117	58	62	26
Wet site 1	86	50	35	4

[1]*Percent of dead trees on infested plot, less the percent of dead trees on a control plot in each stand.*

Table 7.—Estimated total yields (from RMYLD projections) at age 120 (in merchantable cubic feet per acre) in Rocky Mountain lodgepole pine. [Stands now 60 years old; site index 60, thinning interval 20 years (Van der Kamp and Hawksworth 1985.)]

Stand DMR at age 60	Growing stock level 60: Yield	60: % of healthy stand	100: Yield	100: % of healthy stand	140: Yield	140: % of healthy stand
0	3,970	100	5,180	100	6,270	100
1	3,930	99	5,120	99	6,170	98
2	3,640	92	4,200	81	4,390	70
3	2,980	75	3,160	61	3,130	50
4	2,170	55	2,220	43	2,240	36
5	1,420	36	1,110	21	860	14

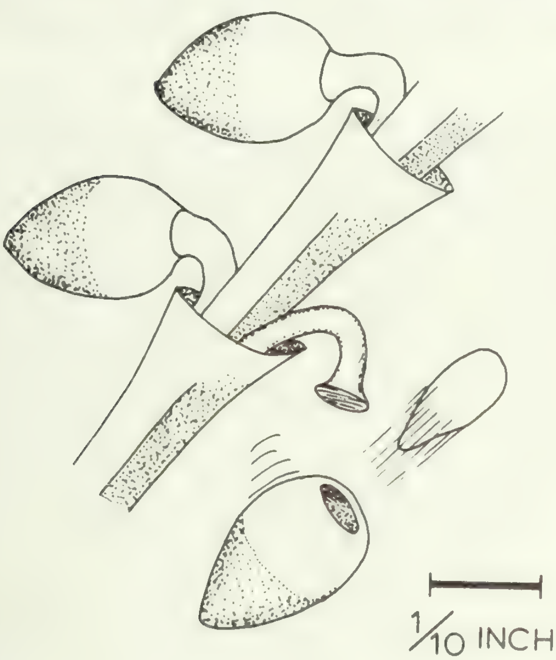
Plate I. Dwarf mistletoe plants, fruits, and seeds.

1. Female dwarf mistletoe plant.

2. Male dwarf mistletoe plant in flower.

3. Closeup of female plant with mature fruits.

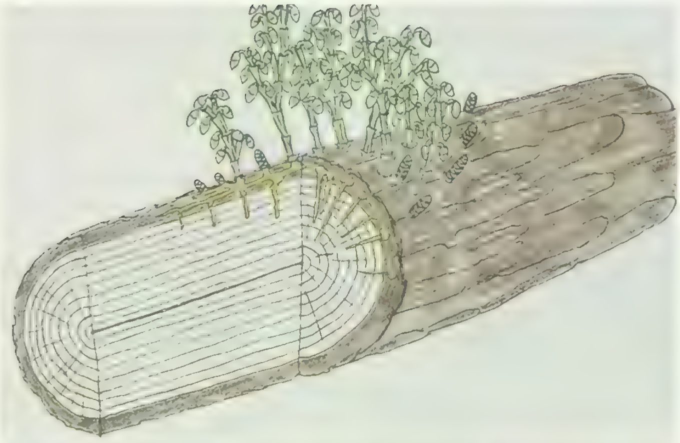
4. Closeup of distal portion of male plant with open flowers.



5. Diagram showing seed expulsion from mature fruit.

6. Photograph of seed expulsion taken at 5 millionths of a second.

Plate II. Dwarf mistletoe infections.



1. Diagram of cross-section of pine stem showing dwarf mistletoe aerial shoots and the mistletoe root (endophytic) system in the cortex and in the xylem (the sinkers).

2. Cross-section of a mistletoe-infected lodgepole pine branch showing the mistletoe endophytic system in the cortex and the radial sinkers in the xylem.

3. Young dwarf mistletoe infection on a lodgepole pine branch showing a fusiform swelling and emerging shoots.

4. Dwarf mistletoe infection on the bole of a young lodgepole pine.

5. Swelling and distortion of the bole of lodgepole pine due to dwarf mistletoe. Such trees are unusable for most timber products.

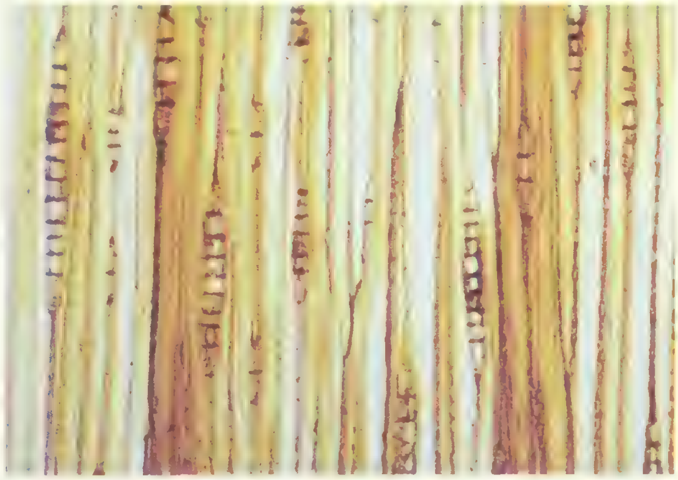
6. Enlarged branches and bole swellings seriously reduce the merchantability of this lodgepole pine.

Plate III. Dwarf mistletoe effects on lodgepole pine.

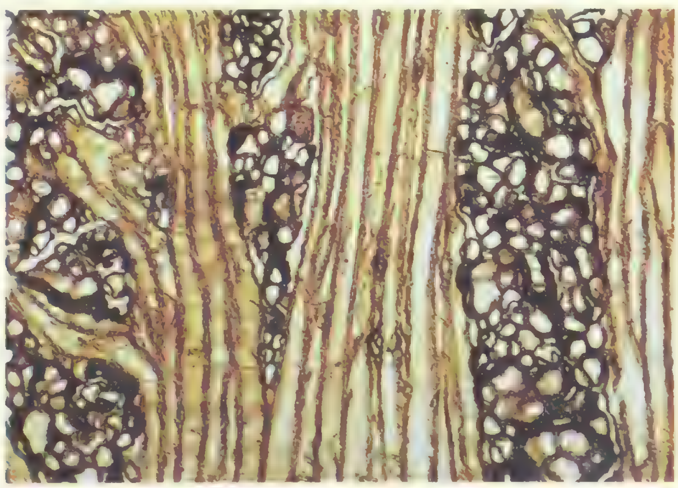
1. Witches brooms are the most obvious symptom of dwarf mistletoe infection.

4. Lodgepole pines heavily infected by dwarf mistletoe typically start declining from the top, form spike tops, and are prematurely killed.

2, 3. These are "stimulation" brooms and are not caused by dwarf mistletoe. Stimulation brooms are frequent in residual lodgepole pines in cut-over areas. See text and Table 10 for details on how to distinguish the two types of brooms.



5. Tangential section of normal lodgepole pine wood.



6. Tangential section of lodgepole pine wood affected by dwarf mistletoe, showing the marked increase in ray volume (consisting of both mistletoe and host tissues) and shorter and distorted tracheids.

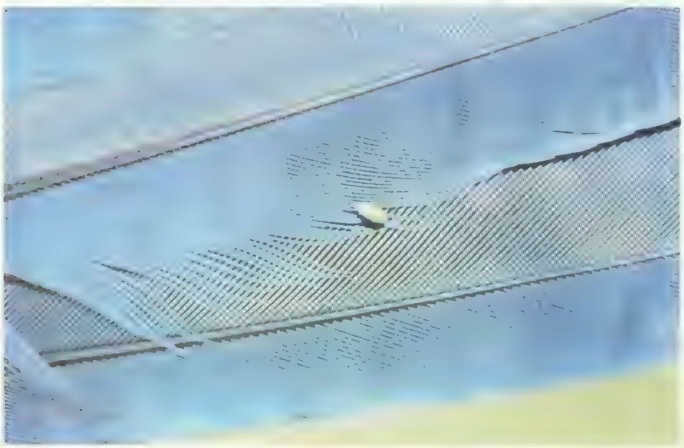
Plate IV. Biotic associates of lodgepole pine dwarf mistletoe.

1. Aecia of the mistletoe rust, *Peridermium bethelii*, a unique fungus that is restricted to mistletoe-infected lodgepole pine. It frequently kills mistletoe-infected branches.

2. Larvae of the hairstreak butterfly, *Mitoura spinetorum*, feed exclusively on dwarf mistletoe shoots, including *Arceuthobium americanum* on lodgepole pine and kills many shoots in some years.

3. Red squirrels frequently feed on the bark of dwarf mistletoe-infected lodgepole pines.

4. Lodgepole pine dwarf mistletoe seeds have been found on at least 10 species of birds, including gray jay, Steller's jay (shown here), and nuthatches.



5. Lodgepole pine dwarf mistletoe seed on Steller's jay.

6. A few mammals also carry dwarf mistletoe seed as shown by this least chipmunk with two seeds (one on the tail and one on the left leg).

Plate V. Dwarf mistletoe-infested lodgepole pine stands.

1. Infected lodgepole pine stand being replaced by Engelmann spruce which is not attacked by lodgepole pine dwarf mistletoe.

2. Heavily-infested mature lodgepole pine stand showing high mortality and spike-topped trees.

3. Use of fire to replace heavily infested lodgepole pine stand.

4. Heavy dwarf mistletoe in lodgepole pine pole stand.

5. Dwarf mistletoe witches brooms frequently act as fire ladders to spread flames from ground fires up into the crowns.

6. Fire-killed dwarf mistletoe-infected lodgepole pine stand being replaced by healthy lodgepole pine reproduction.

Plate VI. Control of lodgepole pine dwarf mistletoe.

1. Application of Ethephon to limit dwarf mistletoe spread in a campground.

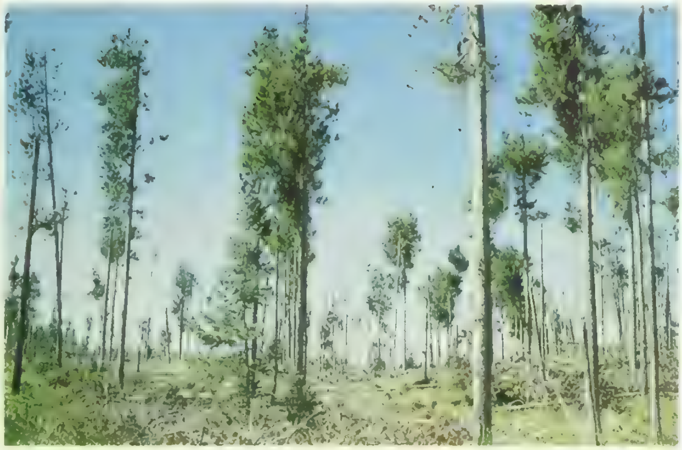
2. Typical dwarf mistletoe plant before Ethephon application.

3. The same plant 5 weeks application showing shoot abscission.

4. Trees heavily infected in the lower half of their crowns before broom pruning.

5. The same trees 6 years after broom pruning. Note the increase in crown density and vigor.

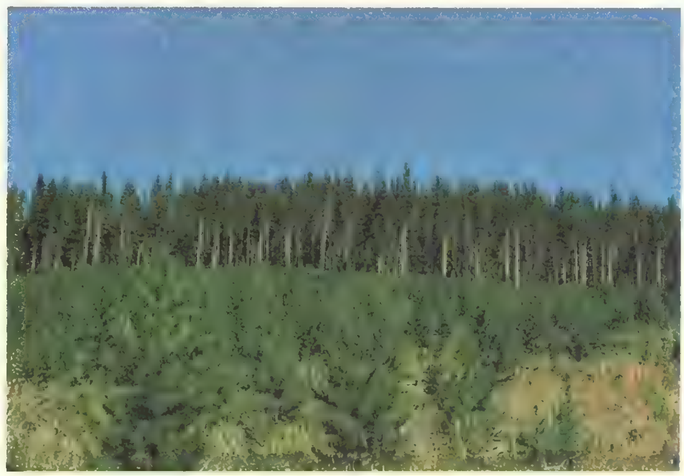
Plate VII. Silvicultural control of lodgepole pine dwarf mistletoe.



1. Residual infected trees in cut-over area. These will be removed when the new young stand is established.

2. Clearcut area in formerly heavily-infested lodgepole pine stand. To minimize dwarf mistletoe spread into the subsequent stand, the clearcut boundaries were placed in mistletoe-free parts of the stand.

3. A Marden Chopper that is used in clearcut areas to remove all residual trees, chop up slash, expose a mineral seed bed, and to scatter lodgepole pine seeds.



4. The same area as in 2 above, nine years after clearcutting showing a mistletoe-free, naturally established stand of lodgepole pine reproduction.

5. A dwarf mistletoe-infected lodgepole pine stand that has been commercially thinned by removing the most heavily infected trees.

6. Optimum silvicultural control in dwarf mistletoe-infested lodgepole pine stands involves application of various types of treatments to specific mistletoe and stand conditions. In this area the disease was so heavy in the stand in the foreground that it was clearcut, in the stand in the background, the disease was less severe so thinning was feasible.

ticipated yields are 36% of comparable healthy stands, but are only 14% for DMR class 5 stands with a GSL of 140 ft^2/ha. The same trend in mean annual increment is shown in figure 19.

The predicted merchantable cubic foot and metric volume from age 60 to 120 in stands with various mistletoe intensities is given in figure 20. The very light class infections (class 1) had no significant effect on yields, but all other infection classes do. Even stands with an intensity of DMR 2 at age 60 will have high infection levels (DMR 5+) by age 120.

Dwarf Mistletoe-Bark Beetle Relationships

Relationships between primary bark beetles (*Dendroctonus* spp.) and dwarf mistletoes are poorly understood (Stevens and Hawksworth 1984). In some beetle-dwarf mistletoe combinations, susceptibility of mistletoe-infected trees is increased; but most of the evidence for lodgepole pine indicates that mistletoe-infected trees are less susceptible to *Dendroctonus ponderosae* (McGregor 1978, Stevens and Hawksworth 1984). The primary reason for this seems to be that mistletoe-infected trees have thinner phloem (Roe and Amman 1970). However, Hawksworth et al. (1983) found little correlation between lodgepole pine phloem thickness and dwarf mistletoe intensity in Colorado. An exception is local bole infections that have thicker bark than adjacent, uninfected parts of the bole (McGregor 1978). In Colorado, at least, there seems to be little or no change in mountain pine beetle susceptibility resulting from mistletoe. Although the effect has not been quantified, the opening-up of stands by mortality caused by mountain pine beetle tends to increase spread and intensity of dwarf mistletoe in the residual trees (Wellner 1978).

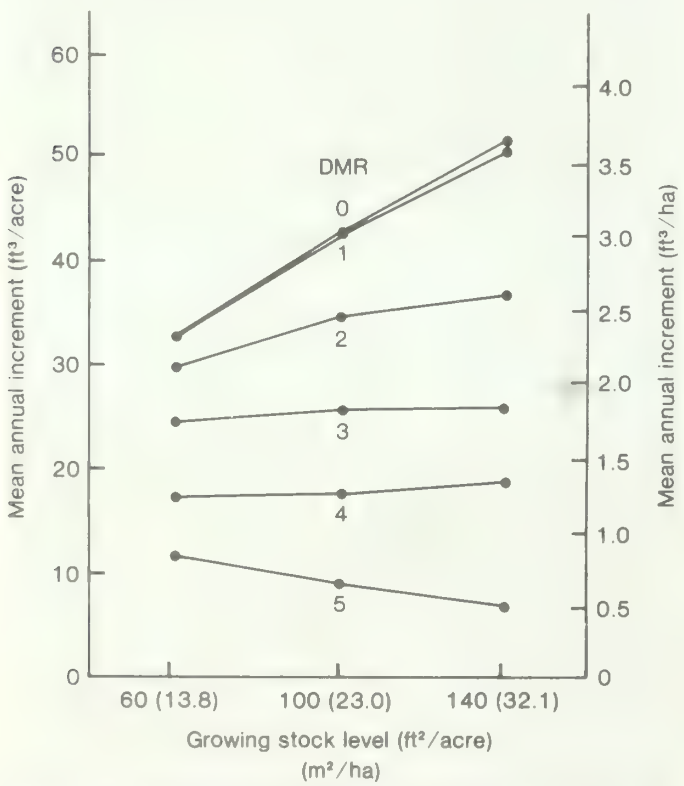


Figure 19.—Relationship of mean annual increment at rotation age (120 years) in relation to three growing stock levels based on six mistletoe rating classes at age 60. Based on site index 60 feet (18.3 m) and thinning interval 20 years (Van der Kamp and Hawksworth 1985).

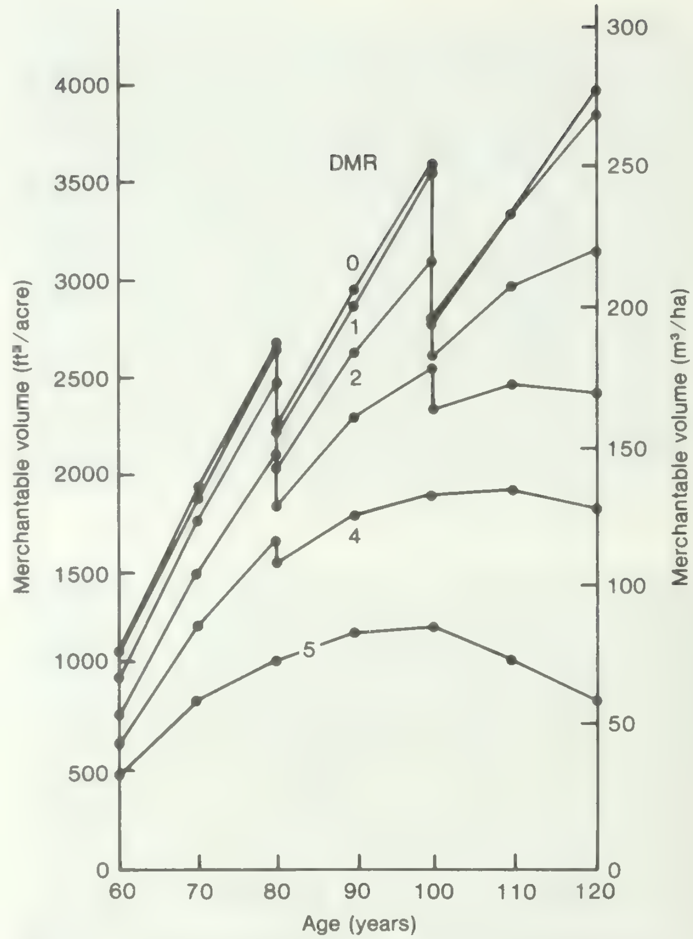


Figure 20.—Projected yields (merchantable cubic feet per acre and meters per hectare) in stands of various infection ratings at age 60. Site index 60 feet (18.3 m), thinning interval 20 years, and growing stock level 100 ft^2/acre (23.0 m^2/ha) (Van der Kamp and Hawksworth 1985).

Seed and Cone Production

Several observations that dwarf mistletoes adversely affect seed and cone production in lodgepole pine have been reported (Plate IV) (Bates 1930, Weir 1916); but only Schaffer et al. (1983b) provided quantitative data. Although they found a trend toward smaller cones, fewer cones per tree, fewer filled seeds, lower germination of filled seeds, and decreased seed size in heavily infested trees (DMR class 5 and 6), only the latter was significantly different (table 8).

Wood Quality

Dwarf mistletoes adversely affect lodgepole pine wood quality in several ways: (1) stems are often swollen and

Table 8.—Seed and cone production in lodgepole pine in relation to dwarf mistletoe intensity (from Schaffer et al. 1983b)

DMR infection class	No. of trees	Tree vigor[1]	Closed cone size[2]	Seed size[2]	Germinated filled seeds
			cm	*mm*	*no.*
0	10	1.7a[3]	2.9a	3.1a	35a
2-4	20	2.9b	2.8b	2.9b	30a
5-6	20	2.9b	2.8b	2.9b	20a

[1]*Vigor estimates based on color and density of needles (1 = dense, mostly green foliage; 2 = fairly dense, partially green foliage; and 3 = sparse, yellow-green foliage).*
[2]*Cone size = (length + width)/2; seed size = (length + width)[2].*
[3]*Numbers followed by the same letter are not significantly different (P = 0.05), Duncan's multiple range test.*

distorted so merchantability is reduced; (2) large knots caused by enlarged mistletoe-infected branches increase degrade of lumber; and (3) wood in infected trees, especially bole infections, is weakened because of a high proportion of ray tissues and shortened, distorted tracheids.

Piirto et al. (1974) found that the modulus of elasticity, modulus of rupture, and work to proportional limit were reduced not only in wood directly invaded by the mistletoe endophytic system, but even in non-infected wood in infected trees. They also found a higher specific gravity, higher percentage of alcohol-benzene extractives, and increased longitudinal shrinkage and increased microfibril angle in infected wood.

While the wood quality is adversely affected by dwarf mistletoe, the practical effects of the parasite on degrade in lodgepole pine lumber recovery are negligible (Dobie and Britneff 1975). A probable reason for this apparent anomaly is that the wood that is most affected is in the outer sapwood and tends to be removed in slabbing.

MANAGEMENT OF MISTLETOE-INFESTED STANDS

As previously discussed, the most important effects of *A. americanum* on its host are reduced growth and vigor and increased mortality. An estimate of commercial forest acreage infested and annual volume loss is presented in table 9. This discussion concentrates on silvicultural practices that can reduce the effects of the disease in forests managed primarily for fiber production and developed sites where tree cover and its condition are emphasized (Plates V, VI, and VII). Very little research has been conducted on the effects of the disease on non-commodity values, such as wildlife, recreation, watershed, and visual quality.

A summary of the options for managing commercial and recreational lodgepole pine forests infested with dwarf mistletoe is presented in figure 21. These options provide only general guidelines; decisions for actual treatments should be made on a stand-by-stand basis.

Management of Stands for Fiber Production

Dwarf mistletoes are most easily and economically treated by silvicultural practices. Dwarf mistletoe control needs to be an integral part of good forest management and practiced as a part of normal stand management activities (Alexander 1986, Alexander and Edminster 1980, Baranyay and Smith 1972, Dooling and Brown 1976, Schmidt and Alexander 1985, Wicker and Hawksworth 1988). Management of infested stands includes the detection, evaluation, prevention, and suppression of the disease. These activities must progress in a planned, timely manner for successful reduction of disease impact on the resource.

Several features of these parasites make them ideal candidates for cultural management (Johnson and Hawksworth 1985):

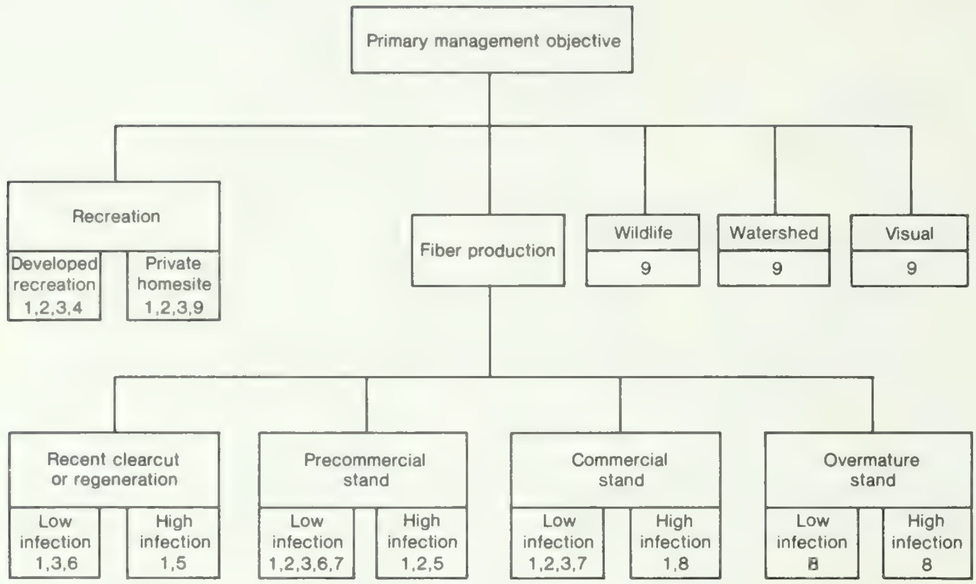
– Dwarf mistletoes are obligate parasites; that is, they require a living host to survive. Once an infected tree or branch is cut, the mistletoe dies. There is no need to destroy the slash for disease control.

– They are generally host specific; that is, they are usually confined to a single host species or group of closely related species. Immune or lightly infected species can be favored during stand treatments (fig. 21).

Table 9.—Annual mortality and growth loss caused by *Arceuthobium americanum* in commercial lodgepole pine forests.[1]

State	Area infested (1,000 acres)	Annual loss (1,000 ft^3)
Northern Rocky Mountain Region		
Montana	1,601	16,964
Northern Idaho	104	1,244
Rocky Mountain Region		
Colorado[2]	518	4,603
Eastern Wyoming[2]	361	4,958
Intermountain Region		
Southern Idaho	919	11,438
Nevada	6	74
Utah	206	2,571
Western Wyoming	242	2,850
Pacific Northwest Region		
Oregon	900	6,462
Washington	360	3,648
Total	5,217	54,812

[1]*These losses were compiled from USDA Forest Service estimates and reports; the states are grouped by USDA Forest Service Region.*
[2]*National forest lands only.*



Management Options

1. Survey for dwarf mistletoe infection
2. Run data through the RMYLD program to predict yields.
3. Favor of plant tree species that are immune or resistant to LPP dwarf mistletoe.
4. Prune witches' brooms and infected branches. Re-examine pruned trees within five years for new and overlooked infection
5. Destroy the stand and regenerate.
6. Fell nonmerchantable infected trees.
7. Sanitation thin.
8. Harvest and regenerate the stand.
9. Do nothing.

Figure 21.—Lodgepole pine dwarf mistletoe management decision key.

– Their life cycles are relatively long compared to other tree disease organisms. The development of mature mistletoe plants from seeds takes 2 to 8 years. From a practical standpoint, these long life cycles mean that the amount of infection increases relatively slowly. If a stand is properly treated, dwarf mistletoe should not be a serious problem in subsequent rotations.

– Dwarf mistletoes spread slowly through stands. Seed dispersal is usually limited to within 60 feet (20 m) from a tall, isolated tree. In even-aged stands, spread is even more limited and averages 1 to 2 feet (0.3–0.6 m) per year. Long distance dispersal of seeds by birds and mammals occurs (Nicholls et al. 1984), but so infrequently that it has little significance to management programs.

– Infected trees and stands are easy to detect because of the presence of dwarf mistletoe plants, branch and stem swellings, and witches' brooms. Heavily infested stands show decline and mortality. However, a complicating factor in some lodgepole pine stands is the frequent occurrence of non-mistletoe brooms termed "stimulation brooms" (Hawksworth 1961) (table 10, Plate III). The stimulation brooms are most common in residual trees left in cut-over areas. Detailed surveys are an essential ingredient of successful control programs (appendix II). Several survey methods have been developed to determine the distribution and intensity of infection (Dooling 1978). The 6-class dwarf mistletoe rating (DMR) system is an easily learned and applied numerical rating system that is widely used throughout the western coniferous forests to assess dwarf mistletoe infection levels in individual trees and stands (Hawksworth 1977) (fig. 22).

Successful strategies have been developed specifically for dwarf mistletoe control (Plate VI). However, these practices need to be integrated into plans that also seek to reduce susceptibility of stands to mountain pine beetle, *Dendroctonus ponderosae*. Both pests need to be consid-

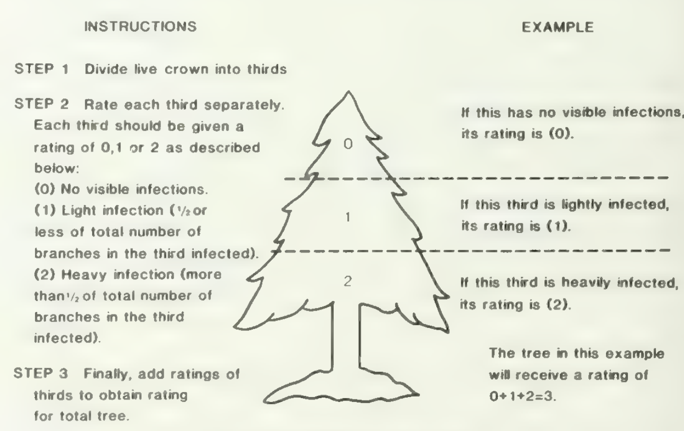


Figure 22.—The 6-class dwarf mistletoe rating system.

Table 10.—Comparison of dwarf mistletoe and stimulation brooms in lodgepole pine (Hawksworth 1961).

Characteristic	Dwarf mistletoe brooms	Stimulation brooms
Presence of dwarf mistletoe shoots or basal cups	Yes	No
Number and orientation of branches in broom	Many branches. Tips point upward.	Relatively few branches. Tips may point upward or sideways.
Crown class of tree	Any	Mainly suppressed or intermediates. Broken-off or spike-topped trees of any crown class.
Abundance	Usually several trees with brooms occur together. May be several brooms per tree.	Broomed trees are usually scattered. Usually few brooms per tree.
Location of brooms	May occur at any height or at any distance from the bole.	Usually below 30 feet and at or near bole.
Occurrence of dead brooms	Usually found on other trees in the immediate vicinity and sometimes on trees with living brooms.	None

ered in multiple resource management, because infestations affect even flow and sustained yield of the timber resource, complicate the conversion of unmanaged to managed forests, disrupt management plans, and affect local, regional, and national economics (McGregor and Cole 1985). In addition, infestations affect recreation and aesthetics, increase fire hazards, and affect watershed management. Mountain pine beetle may increase the proportion of trees infected by dwarf mistletoe through selective attack and resulting tree mortality in the stand, thus increasing the potential spread of dwarf mistletoe in the remaining stand.

In both cases, the objectives of pest management are to reduce pest incidence and intensity and to create a more healthy, pest-resistant forest.

Strategies are designed either to prevent or suppress the disease, depending upon the age of the stand and other management objectives. Because it is much more effective to prevent the establishment of mistletoes than to remove them from infested stands or replace severely infested stands, the priorities in control programs should be placed on prevention.

- Design treatment units to take advantage of natural or manmade barriers (such as roads, streams, non-susceptible forests, openings, or meadows) that prevent reinvasion from adjacent infested stands.
- Remove all infected trees before an area is planted or naturally regenerated.
- Use clearcuts to advantage when harvesting infested stands. Long, narrow cut strips should be avoided.
- Regenerate stands with the shelterwood method using mistletoe-free or lightly infected residual trees. If infected trees must be left (for instance, in areas sensitive to visual quality objectives), they should be removed before regeneration is 3 feet (1 m) tall or 10 years old.
- Select non-susceptible tree species when regenerating a stand or making intermediate entries.

These strategies all reduce the likelihood of dwarf mistletoe spreading into subsequent stands. When a stand is already infested, all infected overstory and then infected understory trees can be removed. This technique, known as sanitation-thinning, can be applied in lightly infested stands. Crop trees should be disease free. However, lightly infected trees may be retained, if necessary, to meet minimum stocking guides. Replacing severely infested stands with healthy stands by clearcutting, roller chopping, or prescribed burning and regenerating may be recommended for heavily infested stands.

The techniques to be used depend on individual stand conditions including stand age and structure, stand density, species composition, number of years to harvest, mistletoe incidence and distribution, and length of time the stand has been infested. Valuable tools—tree and stand growth models and dwarf mistletoe infection models—are available to help the resource manager simulate yields of infected trees and stands (Edminster 1978). Yields for a stand can be predicted under various management regimes and compared to no treatment. By comparing outputs and economic analyses of control costs, the manager can choose the best treatment alternative for each infested stand.

The effects of dwarf mistletoes on a stand depend on a combination of the intensity of infection, stand density, and stand structure. For a given intensity of infection, effects are most pronounced in dense stands. Table 11 shows the estimated percent volume loss to mistletoe

Table 11.—Estimated percent volume loss to dwarf mistletoe in relation to infection intensity and growing stock level. [(Site index 60, thinning interval 20 years) (Van der Kamp and Hawksworth 1985)].[1]

Percent volume loss	Infection intensity (DMR) at growing stock level (ft^2/acre)		
	60	100	140
10	2.1	1.5	1.3
20	2.7	2.0	1.6
30	3.2	2.5	2.0
40	3.7	3.1	2.5
50	4.3	3.6	3.0

[1]*For example, if the forest manager wants to keep mistletoe-caused losses to 10% using a growing stock level of 60, he needs to reduce the residual stand DMR to 2.1.*

in relation to infection intensity and growing stock level. For example, for stands rated as DMR 2 at age 60, estimated volume reduction is about 10%, 20%, and 30% for stands of GSL 60, 100, and 140 ft^2/acre (13.8, 23.0, and 32.1 m^2/ha), respectively. Another way to use this table is to decide what level of loss is acceptable, and then adopt management treatments to keep the infection below the given stand rating. For example, if a 30% loss can be tolerated, stand mistletoe ratings should be kept below DMR 3.2 for GSL 60 ft^2/acre (13.8 m^2/ha), DMR 2.5 for 100 ft^2 (23.0 m^2), and DMR 2.0 for 140 ft^2 (32.1 m^2).

Recently Harvested and Regenerated Stands

The opportunity to control dwarf mistletoe is greatest at the time of final harvest and, secondly, in recently regenerated stands, 5 to 15 years old. Sanitation is the primary emphasis of management in stands of this age.

The greatest dwarf mistletoe threat to regeneration exists where harvest of the previously infested stand was incomplete, and infected residual trees were left standing on the site. These residuals may have been left because they were of no merchantable value. Timber contracts now stipulate felling of diseased, nonmerchantable trees to prevent infection of the regeneration; but, unfortunately, dwarf mistletoe control was not adequately addressed in many past timber sales. Therefore, remedial work is needed in such stands.

Infected residuals over 6 feet (2 m) in height should be felled. Shorter infected trees pose little threat, because infections will be located in the lower half of the crown and dwarf mistletoe seed dispersal will be minimized. Also, bole infections on these trees usually will kill very small trees. All visibly infected trees, however, should be removed during subsequent precommercial stand entries.

Infected trees along the edges of openings should be felled to prevent infection of the regeneration. As a general rule, infected edges should be cut back 60 feet (18 m) before the regeneration is 3 feet (1 m) tall or 10 years old.

If infected residuals have been present for more than about 10 years, the regeneration is probably also infected and will require subsequent sanitation to prevent serious losses in the future. A survey of the regeneration to determine the amount of infection will indicate if sufficient stocking of noninfected and acceptable trees is available for future crop trees. If the infested residual stand has been present for 20 or more years and the regeneration is heavily infected, then it may be necessary to artificially regenerate the site. Guidelines are available based on stand age and average stand DMR (Hawksworth et al. 1977).

Precommercial Stands

The appropriate control measure in stands of this size class should be based on survey data that include the size and location of dwarf mistletoe-infested areas within the stand, the approximate number and location of infected residual trees, and the number of potential crop trees. In most precommercial stands, an intensive, systematic survey provides the best method for collecting these data. Data points (fixed or variable radius plots) should be arranged in a grid pattern over the entire area to insure adequate coverage (appendix II). Spacing between plots should not exceed 10 chains (200 m); 5-chain intervals (100 m) or less are recommended in infested stands. The location of dwarf mistletoe infestations observed when traversing from plot to plot also should be noted.

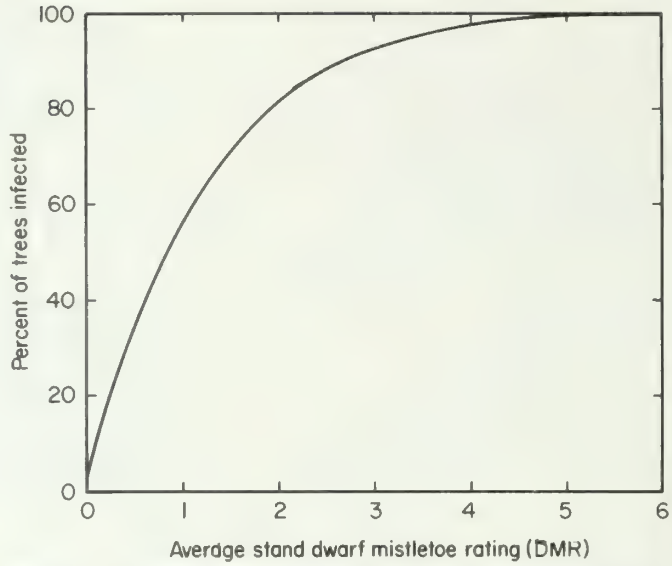


Figure 23.—Relationship between percent of trees infested an average stand dwarf mistletoe rating (DMR) for unmanaged lodgepole pine stands.

Sanitation should be an integral part of all stand entries for thinning, especially in lightly infested precommercial stands from which all overstory or residual infected stems have been felled or killed. The degree of infestation in the stand, not strictly stand age, is the best criterion to decide whether sanitation is practical. A general guide is that stands with more than 40% of the trees infected (average stand rating greater than DMR 0.5) (fig. 23) are too heavily infested to attempt strict sanitation cutting or the removal of all infected trees. In such stands, removal of so many trees will reduce stocking below minimal acceptable levels (Hawksworth 1978, Hawksworth et al. 1977).

The highest priority for precommercial sanitation thinning is stands 10 to 20 years old with less than 40% infection. Potential crop trees should have no visible mistletoe infections. Stands should be thinned and sanitized only if evaluations indicate that minimum acceptable stocking can be achieved with noninfected trees. Severely infested stands that lack acceptable stocking of potential crop trees should be harvested or destroyed (if no products can be salvaged) and the site regenerated. The RMYLD program (Edminster 1978, Hawksworth 1978) can be used to project the growth of the stand to determine whether or not replacement is the best alternative. In stands where potential crop trees average 2 inches

d.b.h. or larger, the order of priority for crop tree selection is:

1. Non-infected dominants and co-dominants.
2. Dominants and co-dominants with mistletoe confined to branches in the lower one-third of live crown (DMR less than 2.0).
3. Intermediates with no visible infection.
4. Dominants and co-dominants with mistletoe confined to less than one-half of the branches in the lower two-thirds of the live crown (DMR less than 3.0). Non-infected intermediates should be selected over DMR class 2 or 3 trees.

If acceptable stocking cannot be obtained within these guidelines, then perhaps the stand should not be thinned. Thinning crews must be able to recognize infections if sanitation treatments are to be effective. Precommercially sanitized stands should not be treated again for mistletoe control until they can be treated during a commercial timber sale.

Suggested guidelines for stocking of sapling and merchantable-sized stands are presented in table 12.

Commercial Stands

Survey information that includes the location and intensity (average stand DMR) of dwarf mistletoe infection is essential to determine the need for control. Yield projections of these stands are invaluable to determine whether infection levels are high enough to influence growth and yield. Sanitation-thinning is recommended only where the stand DMR is 3.0 or less and removal of infected trees does not reduce stocking levels below the accepted minimum. Severely infested stands that lack acceptable stocking of potential crop trees should be harvested early and the site regenerated. If a mixture of non-susceptible species is present, then those species should be favored for regeneration of the stand.

Infested, mature stands that are scheduled for harvest and regeneration offer the greatest opportunity to control the disease by replacement of the stand with mistletoe-free regeneration. Heavily infested stands with sufficient tree seed sources may be clearcut and the cone-bearing tops scattered to obtain natural regeneration, or the slash may be burned and the site planted. Clearcuts

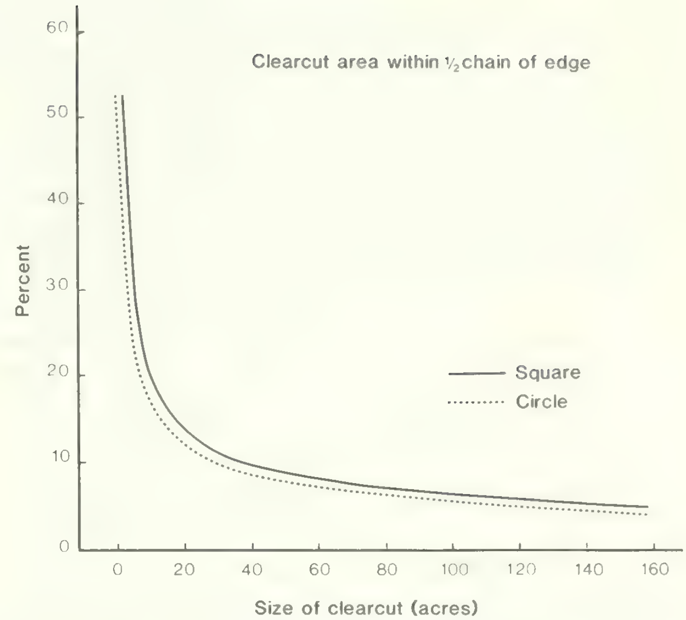


Figure 24.—Relationship between clearcut area and proportion of the clearcut within 1/2 chain (10 m) of the edge, the effective maximum distance of dwarf mistletoe spread.

in infested stands should have as large an area/perimeter ratio as allowable to minimize reinvasion from infected trees along bordering stands. Narrow strips should be avoided. Cutting units should be no less than 20 acres (8 ha) to minimize the edge effect (fig. 24). However, where natural regeneration is desired in areas with non-serotinous cones, smaller cutting units may be needed (Alexander 1986) as border trees provide the only seed source. Wherever possible, cutting boundaries should be located in non-infested stands, non-susceptible timber types, and natural or manmade openings to prevent reinfection of the regenerated stand from adjacent stands.

In areas where retention of infected trees is needed to protect regeneration from adverse climate conditions or where the visual resource is critical to protect, a shelterwood prescription (partial retention of the stand) may be required. However, once the site has regenerated and is established (within 5 to 10 years), all infected trees should be felled or harvested to prevent infection of the regeneration.

Table 12.—Adequate, marginal, and inadequate stocking for disease-free sapling and merchantable-sized stands of lodgepole pine.

Lodgepole pine	Degree of stocking: Adequate	Marginal	Inadequate
Sapling stands (number of disease-free stems per acre)	>250	150–250	<150
Merchantable-size stands (basal area ft^2 of disease-free stems per acre)	>70	40–60	<40

Management of Stands for Other Than Fiber Production

Although the debilitating effects of mistletoe on tree growth and fiber production are well documented, their effects on other resource values have not been fully assessed. The effects on recreation, wildlife, watershed, and visual quality may be positive or negative depending upon the resource manager's objectives for the area in question.

Developed Recreation Sites

There are several different classes of recreation use, including multiple-use areas where recreation is a secondary use and others where it is the primary use (Smith 1978). Others include wilderness areas where management activities are minimized, dispersed recreation areas, and the developed recreation areas, such as campgrounds, picnic areas, ski areas, visitor centers, and other administrative sites. This discussion focuses on the intensively used, developed recreation site where dwarf mistletoe control may be needed to protect various recreation values (Plate VII).

The primary objective of dwarf mistletoe control in these sites is to reduce the negative effects of the disease on tree vigor and longevity and to prevent disease spread into non-infested areas. Effects of dwarf mistletoes on tree growth rates are of less concern, except as growth loss eventually affects tree vigor and mortality. Silvicultural techniques discussed earlier for commercial forests (clearcutting, sanitation thinning) are less acceptable alternatives in developed sites; thus, emphasis is placed on the introduction of non-susceptible species in the understory or on favoring existing non-susceptible species. Pruning mistletoe infected branches, broomed branches, and establishing buffers to prevent spread of the disease can also be used.

Pruning infected branches usually is not practical in commercial stands because of the high cost and difficulty of removing infections; also, repeated treatments are needed to eliminate latent infections. Pruning may be practical, however, to save trees that are needed for stocking and to prolong the life of high value trees in developed recreation, administrative, or home sites (Brown 1978, Hawksworth et al. 1968, Lightle and Hawksworth 1973). Candidate trees for pruning should only be infected in the lower half of the crown, have a DMR of 3 or less, and have no bole infections (where the bole is less than 5 inches in diameter). Infections on parts of the bole over 5 inches have little impact on growth and produce few seeds; therefore, they are of little management concern (Walters 1974). For branch infections on parts of the main stem under 5 inches in diameter, dwarf mistletoe shoots should be at least 4 inches from the bole (Hawksworth and Johnson 1961). Otherwise, the mistletoe's root system will have already entered the trunk and will produce a bole infection.

All live branches in the two whorls above the highest visibly infected branch should be pruned, but try not to remove more than one-half of the tree's live crown. Pruning cannot eliminate all infections because many may be latent, so pruned trees should be re-examined and new or overlooked infections removed in 3–5 years.

Broom pruning may also be effective in prolonging the life of individual trees (Lightle and Hawksworth 1973). The emphasis is on removing branches with witches' brooms rather than removing all visibly infected branches. Studies have shown dramatic recovery in crown vigor in broom-pruned lodgepole pines (Plate VII).

Some research on chemicals that could be applied to infected trees to reduce or kill mistletoe shoots has been reported. Recently, the plant growth regulator ethephon (an ethylene-releasing agent) has been shown to cause premature shoot abscission of *A. pusillum* on spruce in the Lake States and *A. americanum* on lodgepole pine in Colorado (Livingston et al. 1985, Nicolls et al. 1987). This material could be sprayed on infected trees before mistletoe seed dispersal to prevent new infections on existing understory regeneration or planted susceptible tree species. Applications at 3- to 6-year intervals may be necessary because only the aerial portions of the shoots are affected, and resprouting will occur from the endophytic system. This product appears to have promise for reducing dwarf mistletoe spread in recreational forests, but it needs more testing before it can be recommended for operational use.

In planning the location of new recreation sites, dwarf mistletoe infested stands should be avoided, or at least treated, before planning designs are initiated.

Dwarf mistletoe infected trees are more susceptible to attack by secondary bark beetles (*Ips* sp.). Large brooms, dead tops, and witches' brooms are a hazard to recreationists. Opening infested stands only serves to intensify the rate of new infections, resulting in more rapid tree decline and mortality.

Wildlife

Lodgepole pine forests generally are low in variety of plant species and understory vegetation (Basile 1975). The production of forage and nutritional value is limited for game and livestock use (Urness 1985). Alexander (1986) discussed the implications of silvicultural treatments in lodgepole pine on wildlife. Dwarf mistletoe may cause openings in the canopy of infected stands as trees decline in vigor and die, thus creating more favorable conditions for understory plant growth. As these openings regenerate to either the same tree species or other tree species and understory plants, greater vegetation diversity will result. Profound changes in both stand structure and species composition may occur (Tinnin 1984). The mistletoe plants themselves provide a food source for some rodents, birds, and insects (Hawksworth 1975). Mistletoe-killed trees provide nesting sites for snag-dependent bird species. Witches' brooms also provide cover and nesting sites for many birds and mammals (Nicholls et al. 1984).

An example of the potential conflicts between recommendations from dwarf mistletoe control and wildlife

compared with timber production appears in the forest management plan for the Bridger-Teton National Forest in Wyoming (B. Tkacz, personal communication, 1986). The management emphasis is on wildlife, especially elk, and the plan calls for small clearcuts (10 acres or less) in lodgepole pine and leaving reproduction adjacent to residual stands until the young trees are at least 10 feet high, to provide elk hiding cover. Thus, if the residual stands are infected with mistletoe, the parasite will be well established in the young stand by the time the overstory is removed, so the manager must weigh the alternatives of wildlife habitat enhancement against future losses in timber production.

Watershed

Swanson (1985) and Alexander (1986) reviewed manipulation of lodgepole pine forests to augment water yields. However, data on mistletoe effects are lacking. Dwarf mistletoe may indirectly alter streamflow by localizing snow accumulations in open areas created in diseased stands. Hoover and Leaf (1966) noted that more snow tends to accumulate on witches' brooms than on healthy lodgepole pine branches.

Visual Quality

The effects of dwarf mistletoes on aesthetics and visual quality generally would be considered negative through reduced tree vigor, increased mortality, and increased fuel accumulations and susceptibility to fire. Research on pines infected by limb rust has quantified visual quality of diseased trees (Baker and Rabin 1988), but such studies have not yet been made for mistletoe-infected trees. Isolated broomed trees may appear to some recreationists as lending "character" to the landscape and being more photogenic; however, expanses of infected stands are unappealing.

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APPENDIX I. EXAMPLES OF RMYLD YIELD PROJECTIONS FOR SELECTED STANDS

Examples of projected yields in dwarf mistletoe infested lodgepole pine stands using the RMYLD simulation program: Routt National Forest, northern Colorado are given in tables A–D.

A and B show projected yields over 80 years for a stand now 30 years old (site index, 60 feet; trees per acre, 2,700; average d.b.h., 2.0; 30% of trees infected; and stand dwarf mistletoe rating, 0.4). A shows projected yields if the stand has no treatment (2,100 merchantable cubic feet per acre and no board foot volume). B shows the projected yield if the stand is thinned to growing stock level 100 at 20 year intervals (4,410 merchantable cubic feet and 17,800 board feet per acre).

C and D show projected yields over 40 years for a stand now 70 years old (site index, 60 feet; trees per acre, 1,500; average d.b.h., 5.0; 80% of trees infected; and stand dwarf mistletoe rating, 2.1). C shows projected yield if the stand has no treatment (2,810 merchantable cubic feet per acre and no board foot volume). D shows the projected yields if the stand is thinned to growing stock level 100 at age 70 and 90 (3,490 merchantable cubic feet and 11,400 board feet per acre).

APPENDIX II. SURVEY METHODS FOR LODGEPOLE PINE DWARF MISTLETOE

Extensive Surveys

The objective of extensive surveys is to determine the general distribution of dwarf mistletoe over large areas for assessment of losses and long-term planning on a forest-wide and regional basis. The sampling design may be random or systematic. Sampling intensity is usually less than 1% of the area.

Graham (1964) determined the distribution of several mistletoes, including *A. americanum*, in lodgepole pine by sampling townships at 10 locations. The starting point of each sample line was predetermined from a point on the road nearest the center of each township and plots were spread along each line at 10-chain intervals. Sample plots consisted of three concentric circular areas: 1/5 acre for sawtimber, 1/50 acre for pole size trees, and 1/500 acre for saplings.

Various types of roadside surveys have been used for lodgepole pine dwarf mistletoe (Hawksworth 1958a, Hoffman and Hobbs 1985, Johnson et al. 1981). Essentially they consist of driving all passable roads through the selected forest type, recording stand type, size class, and intensity of dwarf mistletoe infestation along a strip adjacent to the road. In addition, plots may be located at intervals within the sampled strip to gather more detailed data on tree diameter, height, age, and dwarf mistletoe rating. This type of survey works well to obtain forest-wide and regional information on the general distribution of the disease and loss at reasonable cost. Infrared aerial photography has been used successfully to detect mortality in black spruce caused by *A. pusillum* (Meyer and French 1967). Direct aerial detection is applicable for *A. americanum* in jack pine (Muir and Robins 1973) but not for lodgepole pine, because brooms are less dense and harder to discern from the air in the latter species.

Intensive Surveys

The objective of intensive surveys is to gather information on the distribution and location of infested stands or parts of stands for management planning and development of suppression programs. The level of sampling intensity usually is at least 10% of the area.

Stand or compartment examinations are the simplest and least expensive to conduct. The number of sample points is limited (about one plot per 10 acres) and may provide the accuracy and precision needed for good suppression planning. A combination of variable and fixed radius plots is used for tree data.

Walters and Brown (1973) and D. H. Brown (1975) compared three sampling techniques for determining presence and infection intensity of *A. americanum* in lodgepole pine: the Stage II compartment examination used in the Rocky Mountain Region (about one plot per 10 acres), a 1% fixed plot sample, and third nearest tree sample on two- and four-chain grids. An analysis of their data compared to a 100% survey indicated the third nearest tree sample on a four-chain grid gave acceptable precision at reasonable cost. However, because of the complex data analyses needed for the third-nearest tree method, fixed-area plots are recommended.

In high value recreation sites, a very detailed, intensive survey may be desired. Strip and plot samples may be used to cover most of the area.

APPENDIX I. PRINTOUT A - YIELDS PER ACRE OF LODGEPOLE PINE WITH NO THINNING, ROUTT NATIONAL FOREST, COLORADO.

SITE INDEX 60 FT. NO THINNING
VALUES IN TABLE ADJUSTED FOR 1.000 STOCKABLE AREA AND .000 DEFECT.

		CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS						
STAND AGE YEARS	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MAI	MERCH. VOLUME CU.FT.	MAI	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	TOTAL VOLUME CU.FT.	MERCH. VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	MERCH. CU.FT. SUBSAWLOG
30	.4	2700	59	2.0	24	600	20	0	0	0							
30	.4	2700	59	2.0	24	600		0		0	0	0	.0	0	0	0	0
40	.6	2434	112	2.9	30	1520	38	0	0	0							
50	.9	2177	145	3.5	34	2320	46	0	0	0							
50	.9	2177	145	3.5	34	2320		0		0	0	0	.0	0	0	0	0
60	1.2	1928	160	3.9	38	2900	48	0	0	0							
70	1.9	1688	170	4.3	42	3450	49	0	0	0							
70	1.9	1688	170	4.3	42	3450		0		0	0	0	.0	0	0	0	0
80	2.6	1439	173	4.7	46	3880	49	0	0	0							
90	3.3	1194	169	5.1	50	4150	46	860	10	0							
90	3.3	1194	169	5.1	50	4150		860		0	0	0	.0	0	0	0	0
100	4 0	963	159	5.5	54	4220	42	1410	14	0							
110	4.7	881	167	5.9	55	4570	42	2110	19	0							
											TOTAL YIELDS			4570	2110	0	2110

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 6.5 INCHES D.B.H. AND LARGER TO 6.0-INCH TOP.
AT AGE 30, 30 PERCENT OF THE TREES WERE INFECTED WITH DWARF MISTLETOE.
CULMINATION OF M.A.I. MERCH. CU. FT.--AGE= 110 MAI= 19.
CULMINATION OF M.A.I. TOTAL CU. FT.--AGE= 70 MAI= 49.

APPENDIX I. PRINTOUT B - YEILDS PER ACRE OF LODGEPOLE PINE, ROUTT NATIONAL FOREST, WITH THINNING IN SAME STAND AS A.

SITE INDEX 60 FT. 20-YEAR THINNING INTERVAL
THINNING INTENSITY-- INITIAL-100 SUBSEQUENT- 100
VALUES IN TABLE ADJUSTED FOR 1.000 STOCKABLE AREA AND .000 DEFECT.

		CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS						
STAND AGE YEARS	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MAI	MERCH. VOLUME CU.FT.	MAI	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	TOTAL VOLUME CU.FT.	MERCH. VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	MERCH. CU.FT. SUBSAWLOG
30	.4	2700	59	2.0	24	600	20	0	0	0							
30	.0+	900	11	1.5	22	110		0		0	1800	48	2.2	490	0	0	0
40	.2	868	52	3.3	28	710	30	0	0	0							
50	.2	853	86	4.3	32	1340	37	0	0	0							
50	.0+	438	57	4.9	33	940		0		0	415	29	3.6	400	0	0	0
60	.1	434	82	5.9	39	1610	42	740	12	0							
70	.2	433	106	6.7	44	2350	46	1700	24	0							
70	.0+	298	84	7.2	45	1900		1500		0	135	22	5.5	450	200	0	200
80	.1	297	104	8.0	49	2560	49	2230	30	9200							
90	.1	297	123	8.7	53	3260	51	2960	35	12100							
90	.0+	211	97	9.2	53	2620		2410		9900	86	26	7.4	640	550	2200	0
100	.1	209	114	10.0	56	3240	52	3040	38	12800							
110	.1	209	131	10.7	59	3890	53	3660	40	15600							
											TOTAL YIELDS			5870	4410	17800	200

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 6.5 INCHES D.B.H. AND LARGER TO 6.0-INCH TOP.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
D.M.R. ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
AT AGE 30, 30 PERCENT OF THE TREES WERE INFECTED WITH DWARF MISTLETOE.
NO NONCOMMERCIAL THINNINGS ALLOWED.
CULMINATION OF M.A.I. MERCH. CU. FT.--AGE= 110 MAI= 40.
CULMINATION OF M.A.I. TOTAL CU. FT.--AGE= 110 MAI= 53.

APPENDIX I. PRINTOUT C - YIELDS PER ACRE OF LODGEPOLE PINE WITH NO THINNING, ROUTT NATIONAL FOREST, COLORADO

SITE INDEX 60 FT. NO THINNING
VALUES IN TABLE ADJUSTED FOR 1.000 STOCKABLE AREA AND .000 DEFECT.

STAND AGE YEARS	DMR	CHARACTERISTICS BEFORE AND AFTER THINNING: TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MAI	MERCH. VOLUME CU.FT.	MAI	SAWTIMBER VOLUME BD.FT.	PERIODIC INTERMEDIATE CUTS: TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	TOTAL VOLUME CU.FT.	MERCH. VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	MERCH. CU.FT. SUBSAWLOG
70	2.1	1500	205	5.0	43	4210	60	740	11	0							
70	2.1	1500	205	5.0	43	4210		740		0	0	0	.0	0	0	0	0
80	2.8	1223	187	5.3	46	4260	53	1150	14	0							
90	3.5	1007	172	5.6	50	4270	47	1570	17	0							
90	3.5	1007	172	5.6	50	4270		1570		0	0	0	.0	0	0	0	0
100	4.2	806	158	6.0	54	4240	42	2100	21	0							
110	4.9	732	164	6.4	55	4500	41	2810	26	0							
											TOTAL YIELDS			4500	2810	0	2810

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 6.5 INCHES D.B.H. AND LARGER TO 6.0-INCH TOP.
AT AGE 70, 80 PERCENT OF THE TREES WERE INFECTED WITH DWARF MISTLETOE.
CULMINATION OF M.A.I. MERCH. CU. FT.--AGE= 110 MAI= 26.
CULMINATION OF M.A.I. TOTAL CU. FT.--AGE= 70 MAI= 60.

APPENDIX I. PRINTOUT D. YIELDS PER ACRE OF LODGEPOLE PINE, ROUTT NATIONAL FOREST, WITH THINNING IN SAME STAND AS C.

SITE INDEX 60 FT. 20-YEAR THINNING INTERVAL
THINNING INTENSITY-- INITIAL-100 SUBSEQUENT- 100
VALUES IN TABLE ADJUSTED FOR 1.000 STOCKABLE AREA AND .000 DEFECT.

		CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS						
STAND AGE YEARS	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MAI	MERCH. VOLUME CU.FT.	MAI	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	TOTAL VOLUME CU.FT.	MERCH. VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	MERCH. CU.FT. SUBSAWLOG
70	2.1	1500	205	5.0	43	4210	60	740	11	0							
70	.3	364	32	4.0	40	630		0		0	1136	173	5.3	3580	740	0	740
80	.5	358	55	5.3	44	1210	60	330	13	0							
90	.8	355	77	6.3	48	1840	60	1130	21	0							
90	.5	338	76	6.4	48	1810		1130		0	17	1	3.3	30	0	0	0
100	.8	337	98	7.3	51	2500	61	2010	28	0							
110	1.1	337	118	8.0	54	3170	62	2750	32	11400							
											TOTAL YIELDS			6780	3490	11400	740

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 6.5 INCHES D.B.H. AND LARGER TO 6.0-INCH TOP.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
D.M.R. ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
AT AGE 70, 80 PERCENT OF THE TREES WERE INFECTED WITH DWARF MISTLETOE.
NO NONCOMMERCIAL THINNINGS ALLOWED.
CULMINATION OF M.A.I. MERCH. CU. FT.--AGE= 110 MAI= 32.
CULMINATION OF M.A.I. TOTAL CU. FT.--AGE= 110 MAI= 62.

Hawksworth, Frank G.; Johnson, David W. 1989. Biology and management of dwarf mistletoe in lodgepole pine in the Rocky Mountains. Gen. Tech. Rep. RM-169. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.

This publication synthesizes the vast literature on lodgepole pine dwarf mistletoe (*Arceuthobium americanum*) and adds some new information on biology of the parasite. Although dwarf mistletoe has been recognized as a serious parasite of lodgepole pine for more than 75 years, its routine operational control through forest management has been primarily a development over the past two decades. This report discusses silvicultural control of dwarf mistletoe in various types of stands where fiber production is the primary goal, and also in forests used mainly for recreation.

Keywords: *Arceuthobium, Pinus contorta,* damage, control, tree diseases, dwarf mistletoe, lodgepole pine.

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization

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United States
Department of
Agriculture

Forest Service

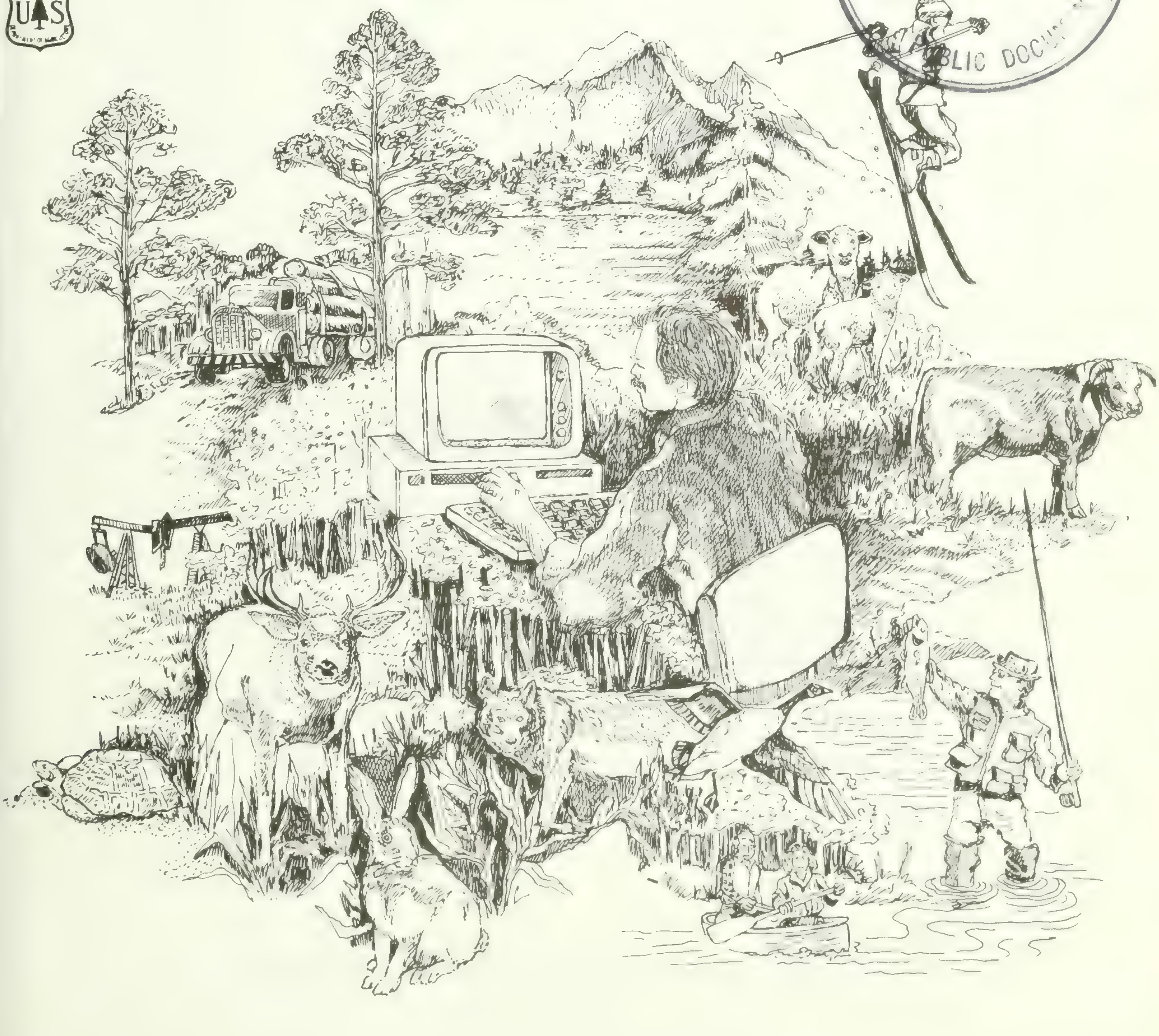
**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-170**

Review of Critiques of the USDA Forest Service Land Management Planning Process

**Tony J. Baltic
John G. Hof
Brian M. Kent**



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Baltic, Tony J.; Hof, John G.; Kent, Brian M. 1989. Review of critiques of the USDA Forest Service land management planning process. General Technical Report RM–170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.

This report reviews a sampling of the literature evaluating the USDA Forest Service land management planning process. The Forest Service planning process and what constitutes an evaluation or critique of this process are defined. Relevant critiques are then reviewed individually by interest group category. The reviews, which are structured to provide insight as to the most common themes, conclusions, recommendations, and methodologies, lead us to conclude that a diversity of views dominates while consensus is limited. Perhaps the only consensus identifiable at this time is that the planning process includes a strong political element that has not been adequately considered.

Keywords: land management planning, forest planning, FORPLAN, planning process.

USDA Forest Service
General Technical Report RM-170

April 1989

Review of Critiques of the USDA Forest Service Land Management Planning Process

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Abstract

This report reviews a sampling of the literature evaluating the USDA Forest Service land management planning process. The Forest Service planning process and what constitutes an evaluation or critique of this process are defined. Relevant critiques are then reviewed individually by interest group category. The reviews, which are structured to provide insight as to the most common themes, conclusions, recommendations, and methodologies, lead us to conclude that a diversity of views dominates while consensus is limited. Perhaps the only consensus identifiable at this time is that the planning process includes a strong political element that has not been adequately considered.

[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Review of Critiques of the USDA Forest Service Land Management Planning Process

Tony J. Baltic, John G. Hof, and Brian M. Kent

Introduction

In "the first major forest policy forum" (LeMaster and Popovich 1977), convened soon after passage of the National Forest Management Act of 1976 (NFMA) which amended the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), participants generally agreed that congressional policy direction for federal forest management was inadequate prior to NFMA. While there was less consensus as to the scope of direction needed, it was judged premature to evaluate the impacts of NFMA or to offer any solutions. John R. McGuire (1982), Chief of the Forest Service when NFMA became law, described the direction mandated by NFMA as a "trial process" authorized by Congress in the hope that it would satisfactorily answer the question of what to do with the national forests. He suggested that this question will require lengthy debate because the directives in NFMA involve planning "processes that in past years were never attempted or processes that have never passed beyond concept into practice."

The debate has begun, as witnessed by the preparation of numerous analyses and critiques concerning various aspects of the Forest Service's land management planning process. However, there has been no comprehensive internal Forest Service evaluation of the process to assess its overall performance and determine if any changes are needed. The Forest Service has now essentially completed an initial round of the planning process and is about to undertake such an assessment to prepare for the next round of planning. The objective of this literature review is to summarize past critiques of the Forest Service's land management planning process so as to provide input into the upcoming Forest Service critique.[2]

The land management planning process is defined by the

- *legislation* that interprets and codifies the original intent of RPA and NFMA
- *regulations* that transform the original intent defined in the legislation into planning steps for developing, adopting, and revising land and resource management plans for the National Forest System
- *internal guidelines and directives* that further clarify the intent and regulations to facilitate plan development at the forest level.

A critique might include evaluation of (1) how effectively the land management planning process transformed the original intent of NFMA into clear components that could serve as guidelines for implementation; (2) how effectively and efficiently these components facilitated the production of forest plans; and (3) how useful the completed forest plans were as management tools for the implementation of the original intent of NFMA by line officers and resource specialists on the ground. The critical examination of any single issue that has, through the planning experience so far, proven to be controversial and the subject of substantial debate also constitutes a critique.[3]

Relevant critiques, which were reviewed individually, are categorized by Forest Service public (interest group).[4] The reviews are structured to answer the following basic questions:

- *who*—identity of specific public or individual who did the critique
- *why*—purpose or focus of the critique
- *how*—the methodology used
- *what*—conclusions and recommendations.

The discussion of methodology includes such aspects as whether the critique was subjective or objective; description of analytics, empirics, and evaluation criteria; and source and quality of data and facts.

Because of the broad definition of what constitutes a critique and the detail required to meet the review objective, the literature review is limited to a sampling from the range of all past critique efforts. The Literature Cited section references the critiques reviewed in this report.

Review of Critiques

Conservationist, Environmentalist, and Preservationist Groups

The Wilderness Society (1987) prepared a critique it termed "the first attempt at a nationwide analysis of the Forest Service plans." The Society is a nonprofit, membership organization dedicated to the advocacy of wilderness values and an American land ethic. The focus of the Society's analysis is on the results of the planning process as outlined in the completed forest plans. The

[2] *This paper reviews critiques from the available literature. The review of administrative appeals of forest plans is beyond the scope of this document.*

[3] *For example, the issue of below-cost timber sales, although not directly referred to in the law or regulations, is indirectly related to the planning process primarily through the economic efficiency provisions of Part 219.14 of the regulations (timber resource land suitability), and it also has implications for other components as well. Below-cost sales have proven to be a major concern in the planning and management on National Forest System lands, and assessments concerning this issue, therefore, constitute a critique for purposes of this literature review.*

[4] *Separate critiques by the same individuals or by representatives of the same group or organization may be combined into a single review.*

critique raises no questions concerning procedural matters. Primary issues of concern are logging and road construction levels, below-cost timber sales, environmental protection and resource stewardship, and wildlands protection. The critique questions the usefulness of the completed forest plans and expresses major concerns about the internal guidelines and directives component of the planning process. The Society sees no problem with the legislation or regulations in this regard.

More specifically, the Wilderness Society states that the NFMA "clearly" mandates reforms of past Forest Service practices, which emphasized commodity production, especially timber, at the expense of other forest resource values and environmental quality; these reforms, it states, are established in "detailed standards" in the legislation and regulations. The Society asserts that the Forest Service has "misinterpreted or ignored the NFMA's mandate." The critique cites results from the forest plans and sections of the legislation and regulations to support its claims that instead of protecting and enhancing the productivity and benefits of all forest resources as mandated by NFMA, the agency continues to manage the national forests principally for commodity production, resulting in resource damage and taxpayer loss.

An example of the analytic style utilized in this critique involves the issue of timber resource land suitability. Section 6(k) of NFMA is quoted with regard to the limitations it places on designating suitable timberland. The intent of this section, in the Society's view, is the elimination of past Forest Service practices that included logging on physically and economically unsuitable lands. The analysis reasons that such limitations should result in the land suitability base being significantly lower than in the pre-NFMA era. However, the empirics show this base is reduced by less than one-half of one percent, nationwide (table 1). The analysis further asserts that these results indicate that physically and economically unsuitable lands remain in the base.

The Wilderness Society also asserts that these unsuitable lands are being scheduled for development. For example, it considers the number of "below-cost forests" (forests whose timber sale expenditures exceed receipts) an indication of excessive logging on uneconomic lands.

Other evaluation criteria used in the critique are more qualitative in nature, gleaned from the text of the law and regulations and the forest plans. For example, the Society cites the NFMA sections requiring commercial forest lands to be classified as unsuitable for timber production if the Forest Service cannot "insure" that their watersheds are protected from irreversible damage. Then, examples from the forest plans are cited that show the Forest Service relies mainly on "best management practices" (BMPs) and other mitigation techniques to prevent environmental damage. The Society asserts the Forest Service is not only deemphasizing the method of protection mandated by NFMA—taking unsuitable lands out of production—but is proposing methods that are either the same as those used prior to NFMA (i.e., BMPs) or are unproven and cannot "insure" environmental protection. Similar evaluations are applied to such controversial issues as biological diversity, clearcutting, and Forest Service rationalization for below-cost timber sales.

The Society also quotes Hubert Humphrey, a principal sponsor of the NFMA, and other congressional leaders in the debate over NFMA as to the central importance of protecting and enhancing noncommodity forest resource values. The basic conclusion of this critique is that the results of the forest plans do not conform with the intent of NFMA. The critique is limited to a reaction to the results of forest planning, without addressing the planning process or analyses per se. The recommendations do not call for specific outcomes but are broadly defined prescriptions for changing plan results so that a higher priority is assigned to the enhancement and protection of noncommodity forest resources and values.

The National Wildlife Federation and the American Forestry Association (1988) collaborated on a document expressing their shared views on the "current problems plaguing the management of the National Forest System...." The National Wildlife Federation and the American Forestry Association are nonprofit conserva-

Table 1.—Summary of Forest Service land classifications in forest plans.

Forest Service Region	Land classification: Commercial forest land (pre-NFMA)	Land classification: Suitable for timber production (NFMA plans)	Change from commercial to suitable in NFMA plans	
	Thousands of acres			Percent
Northern	8,676	9,074	+398	+4.6
Rocky Mountain	4,185	5,068	+883	+21.1
Southwestern	3,935	3,721	-214	-5.4
Southern	8,653	9,106	+453	+5.2
Eastern	8,598	6,472	-2,126	-24.7
Alaska	1,071	968	-103	-9.6
Intermountain	3,239	3,463	+224	+6.9
Pacific Southwest	4,250	5,158	+908	+21.4
Pacific Northwest	4,971	4,339	-632	-12.7
Total	47,578	47,369	-209	-0.4

tion education organizations dedicated to the advancement of "intelligent" management, use, and protection of all natural resources.

In this report, these organizations suggest the planning process has failed because it has not solved controversies but has "simply provided a new arena for fighting them out." They list a range of problems they see as the root of most controversies. The problems are essentially results oriented, particularly with respect to timber production. In their view, the underlying problem is formulated as a simple question, "...how, and for what, are the National Forests to be managed?" They suggest most of the public would answer that the national forests should "be managed with whatever mix of products, services, and public uses that is least available from the private lands and other public lands of the region, seeking the balance that makes them truly different." They argue that this answer is representative of a shift in how the public values the attributes of the national forests. In identifying the reasons for this change the report states,

> These changing perceptions about the values of the National Forest System arise from the fact that the resources which are most scarce, and most valuable today, are essentially different from what was scarce and valuable in the past.

The inference is drawn that the commodity production opportunities and capabilities of our nationwide natural resource base are relatively abundant and even expanding compared with attributes such as biologically diverse ecosystems, which are decreasing and essentially only available on national public resource lands. These organizations assert that new goals for the National Forest System and a new mission for the Forest Service that are responsive to these changes and growing values must be clearly defined. This is the essence of the debate about national forest planning as framed by these two organizations, and they go on to list some questions concerning the roles of the National Forest System, the Forest Service, Congress, and the various publics in order to stimulate the debate.

H. Michael Anderson (1987) addresses the impact on the Forest Service planning process of an increasing public concern for water quality and recent national water quality legislation. Anderson is a forest planning specialist with the Wilderness Society. Anderson cites a poll of public attitudes about national forest uses that indicates water quality protection may be considered the single most important use. He describes the antidegradation requirements mandated under the Clean Water Act (CWA). The EPA and state governments were assigned authority to apply CWA standards and are now taking initial steps to implement that process. Anderson asserts that the Forest Service planning process is not consistent with the new requirements. He argues that the current planning process results in the establishment of logging and other commodity targets while water quality protection is addressed with BMPs. However, the standards of CWA represent water quality targets to be met, not damage to be mitigated. Thus, Anderson argues, the Forest Service must revise its planning principles and procedures to treat water quality as a target required by law. He states, "...the traditional rules of water quality protection and commodity development have been fundamentally reversed."

Although case law and legal clarification have yet to establish the final implementation process for CWA, Anderson recommends that the Forest Service take the initiative to work with state governments and the EPA to develop standards and monitoring systems for national forest lands and to identify specific national forest waters and fisheries needing immediate protection or restoration. He suggests that specific provisions resulting from this collaboration should be integrated into the NFMA planning process principles and procedures.

William E. Shands (1986) expresses his opinions about the strengths, weaknesses, and limits to the RPA Program, Assessments, and Annual Reports and makes some recommendations for improvements. Shands is a senior associate with the Conservation Foundation who specializes in forest policy. Shands bases much of his evaluation of the RPA process and its components on interviews with a cross section of the relevant constituency. Results from the interviews suggest planning is generally supported and the RPA documents are considered useful. Major criticisms involve (1) the discrepancy between RPA targets and Forest Service budgets, (2) program complexity, and (3) the neglect of contemporary issues. Shands emphasizes that it was not the intent of RPA to commit Congress or the administration to program targets. He also suggests that the problems articulated reflect tensions that are healthy for a dynamic planning process, and he cautions against expecting purely rational decisions when RPA is essentially a political process.

Shands recommends that each 5-year program be designed as a strategic plan encompassing a view of both short-term and future issues. He urges a stronger connection to "larger socioeconomic and environmental issues." Shands suggests that future assessments use the 1984 supplement as a model, with the added refinements of consolidating the discussion by resource category and adding an executive summary. Finally, the author recommends incorporating the annual report in the process as an extension to the strategic strategy—an annual update of the program according to changing conditions and needs.

M. Brock Evans and Connie M. Mahar (1982) discuss departures from sustained yield from a conservationist's perspective. They are vice president and assistant to the vice president for national issues, respectively, with the National Audubon Society. In their discussion of departures from sustained yield, Evans and Mahar focus on congressional intent and the results of departures. The authors assert that departures were intended to be "aberrations" and not the norm. They view the present departures question as an old-growth issue, charging that departures have turned into a vehicle for eliminating old growth for short-term economic gain. Evans and Mahar present a scenario depicting scheduled departure programs as indicative of the shifting of the burden of proof

Table 2.— Comparison of RPA alternative with proposed alternatives, Region 2 (August 1986).

Decade	Board feet			Cubic feet		
	RPA	Proposed	Percent	RPA	Proposed	Percent
Decade 1	514.05	437.23	−14.9	118.75	102.51	−13.7
Decade 2	568.58	489.85	−13.8	131.73	114.79	−12.9
Decade 3	579.98	517.65	−10.7	134.39	121.21	−9.9
Decade 4	603.93	551.30	−8.7	139.49	128.98	−7.5
Decade 5	630.48	579.60	−8.1	145.83	135.51	−7.1

in a way that Congress did not intend. They also imply that the timber land suitability provisions of NFMA are violated by current departure policies. Evans and Mahar then outline the multiple-use benefits of old-growth forests and the adverse impacts resulting from their liquidation. They argue old-growth forests are nonrenewable and are important resources in and of themselves.

Timber Industry

The views of the National Forest Products Association (NFPA) concerning NFMA and the planning process were prepared by its NFMA Oversight Task Group (1986)[5] and Mark Rey (1986), the Association's vice president of public forestry programs. The NFPA is a national trade association representing member forest landowners and managers and wood products manufacturers. The NFPA material is indicated to be a preliminary evaluation outlining the general problems with NFMA and the forest planning process; it does not link these problems with specific provisions of the Act or regulations and makes no official recommendations.

The main focus of the Association's critique are forest plan results that it asserts propose unjustified and "dramatically" reduced timber sale programs. Adverse implications cited include failure to meet national timber demand projections, loss of competitiveness for domestic producers dependent on federal timber, and economic instability for local timber-dependent communities. The critique also lists many other problems associated with reduced timber sales.

The NFPA asserts the intent of the Resources Planning Act of 1974 (RPA) is to assure a supply of commodity resource outputs adequate to meet national demand, and the NFMA amendment to RPA is intended to set individual forest target shares of national RPA goals. If these targets cannot be met, the forests are to explicitly indicate to Congress why. Furthermore, in NFPA's view, NFMA is a mandate authorizing the practice of even-age silviculture (clearcutting) to facilitate the achievement of national RPA goals. The NFPA bases its critique primarily on the failure of forest plans to meet RPA goals, and it presents empirical evidence using Forest Service data to show the discrepancy. For example, the proposed sales schedules for Region 2 are shown to fall from 7 to 15 percent short of the RPA goals (table 2).

The NFPA extends its analysis to the consequences of reduced timber sales by equating the percentage decline in harvest levels with jobs and annual payments to counties lost. The NFPA supports its interpretation of original intent by quoting from the Senate testimony of John McGuire, then Chief of the Forest Service, endorsing the proposed NFMA legislation in terms of its relevance to present (historical) timber management practices and RPA harvest goals (Joint Hearings of Senate Committee on Agriculture and Forestry, Committee on Interior and Insular Affairs, March 16, 17, 22, 1976, p. 288–291).

Another central NFPA theme is that the NFMA objectives, as established in the law, regulations, and guidelines, are "vague and ambiguous" with respect to timber harvest and community stability but are more clearly defined for environmental standards. They assert that this discrepancy in transforming intent into the law and rules, along with a planning process that requires an interdisciplinary approach to forest planning, has resulted in a noncommodity bias in the forest plans. Another major weakness, in their view, is the lack of a clear link between national RPA goals and the planning process as carried out on individual forests. In particular, because the law and rules are not clear on the original intent of Congress, forests have not explained why RPA timber targets have not been met.

In NFPA's view, other perceived problem areas are as follows: (1) the procedures for setting management objectives and making decisions are confusing, unclear, and too broadly defined; (2) the public participation process is unclear and subject to abuse—opportunities for public review and comment on the intermediate planning steps and on policies formulated at the national office level are not made available or are ignored; (3) the analytical planning procedures are too complex, expensive, and time-consuming and the data base utilized is of questionable validity. A general NFPA conclusion is that a substantial number of the problems with NFMA arise because the regulations and guidelines are process-oriented instead of decision-oriented. No specific recommendations were included in the NFPA critique pending further study and consultation with membership.

John L. Walker (1983), representing the Simpson Timber Company of Seattle, Wash., prepared a critique of the NFMA planning process for presentation at a conference on critical policy issues in U.S. forestry. The critique involves an analysis of the economic efficiency criteria utilized in Forest Service planning.

[5]*National Forest Products Association. NFMA Oversight Task Group. 1986. Overview of problems with the NFMA planning process (unpublished paper—not for circulation). 16 p.*

Walker asserts that the Forest Service planning process is seriously flawed because the economic efficiency objective that congressional intent clearly called for has, in fact, been replaced by an irrational imposition of certain traditional Forest Service management constraints. In Walker's view, the correct economic efficiency objective would produce outputs consistent with the outcome of competitive markets. He discusses the theory of economic optimality in terms of the maximization of net social benefits and the central role interest rates and prices play in achieving this optimality. He further argues that this scenario represents the results of an efficient free market operation. Walker then charges that the Forest Service ignores the importance of interest rates and prices in establishing the requisite economic efficiency criteria for planning and that the agency's real objective continues to reflect the traditional emphasis on sustained yield and other harvest flow constraints. He describes the work of the interdisciplinary planning teams as negotiating the specifications of "preconceived" constraints, most notably the various harvest flow constraints (along with resource and land use allocations) before any alternatives are developed. He charges that, in this way, the Forest Service avoids considering the costs and benefits associated with the constraints. Walker suggests that the Forest Service can follow this procedure because of the ambiguities and inconsistencies in the legislation and regulations and also because of the broad discretion given the agency by these laws and rules. He also points out that while the Forest Service sets the output level through allowable cut constraints, it ignores price effects by assuming the stumpage demand curve for individual forests to be horizontal. Finally, Walker is critical of the analytical model (FORPLAN) used by the Forest Service. His general conclusion is that the major change in forest management and planning mandated by NFMA is that economic efficiency considerations now have priority over the traditional objectives concerning harvest flow constraints. He also asserts that the allowances for departures were instituted to permit this restructuring.

Ralph Peinecke (1982) argues that departure analysis should be made the "rule" in national forest planning rather than the "exception" it currently is. Peinecke is vice president of timberland resources for Boise Cascade Corporation. Peinecke draws a distinction between the concepts of sustained yield and nondeclining even flow yield. While sustained yield is law, he contends nondeclining flow is Forest Service policy that interprets the sustained yield law. In his view, the Forest Service has wide discretion in this interpretation with respect to departures from nondeclining flow. Peinecke evaluates the merits of departure analysis in terms of "the Forest Service's basic objectives of nondeclining even flow policy." He cites examples from forest industry practices, the economic literature, and national forest plans as evidence to support a conclusion that "nondeclining yield policy is neither necessary nor always sufficient to realize the objectives established for its implementation." A central theme running throughout Peinecke's analysis is the promise of technological advancements in forestry and the opportunities lost by not fully utilizing our technological capabilities through departures. He calls for regulations that put more emphasis on departure programs and a more rational political process within which such decisions can be made.

Professional Forestry Societies

In its report, the Renewable Resources Planning Act Task Force of the Society of American Foresters (1987) outlines several specific recommendations for changes in the RPA process and law. Although the Task Force views the results of RPA planning to date as flawed, it believes the planning process as originally intended is a valuable exercise and it is "essential" that it be made to work. The following is a characterization of some of the more substantive changes in the existing planning process framework that the Task Force believes will result in more effective future RPA Programs.

1. The Program must respond directly to the Assessment findings. Budgetary considerations should not shape the Program. The Program can then be used as a baseline case for analyzing the effects of alternative budget levels.
2. An accounting system should be developed that would track the expenditures for each Program element.
3. The Annual Report of the Chief should become a principle planning document. Its function should be to describe the consequences of deviations from the budget necessary to meet the goals and targets of the recommended Program and forest plans.
4. Alternative Programs, each responsive to the Assessment but favoring different combinations of outputs, should be developed to further enhance a trade-off analysis that would be framed in terms of both budget levels and types of outputs.
5. The Assessment should be less textual and more graphic.
6. The role of economic analysis should continue to be enhanced in the process.
7. Forestry professionals outside the agency should have a larger role in program document development and technical review. This would improve the quality and credibility of RPA documents and also increase the commitment of the professional forestry and conservation community to the RPA process.

These recommendations have been adopted as the official position of the Society of American Foresters.

Natural Resource Consultants

The unavoidable political and institutional influences on the RPA/NFMA planning process are discussed by Cortner and Richards (1983a), Cortner and Schweitzer (1981, 1983b, 1983c), and Schweitzer et al. (1984). They also discuss why and how these should be integrated into

the objective/technical legal mandate for forest planning. Hanna Cortner, formerly a natural resource policy specialist with George Banzhaf and Co. in Tucson and adjunct associate professor, School of Renewable Natural Resources, University of Arizona, Tucson, collaborated with Dennis Schweitzer, an economist with the USDA Forest Service, and others. Their papers review the general literature concerning administrative and organizational behavior with respect to planning.

Cortner and Schweitzer describe RPA/NFMA as "the most complete statement of a fully rationalistic planning process available." They then describe the decision-making process in the "real-world" as significantly influenced by (nonobjective) value judgments because the "scientifically validated, empirical knowledge base underlying forest planning is typically, rather than exceptionally inadequate." In their view, the diversity of values competing to facilitate the analysis and influence the results makes forest planning "fundamentally a political process that defines winners and losers rather than simply a technical enterprise to define truth...." They caution that an insufficient awareness of this political aspect of planning and the constraints it imposes on the analysis and expected results will lead to a failure of the planning process.

Cortner and Schweitzer do not make any specific recommendations, but they present some generalized concepts depicting how greater awareness of the political aspect of the planning process could increase the chances for improving forest management. For example, they point out the pitfalls of the present public participation process that result from its procedural and technique orientation. They assert that an approach emphasizing the negotiation of mutually acceptable tradeoffs between publics would have a greater chance of producing results acceptable to all interested parties (thus reducing the probability of costly litigation and remanded plans). Accordingly, this approach would require greater knowledge of political concepts and skills on the part of the Forest Service's planning personnel. Cortner and Schweitzer argue further that the "centralized rationality" of RPA/NFMA necessitates "political adjustments" within the agency. This critique may be summarized by their statement,

> If not explicitly recognized, the lack of a fit between the theoretical model and the type of RPA plan that is realistically possible to present to the public can lead to a distrust of all planning. Then the goals of public national planning for forest resources will remain elusive and its accomplishments ephemeral.

Randal O'Toole (1988) posits that prescriptive legislation such as RPA/NFMA treats the symptoms of management inefficiencies and environmental degradation and not the causes. Thus, he concludes, they are bound to fail. He suggests that a "radical rethinking of traditional environmental concepts" is required. O'Toole is the director of Cascade Holistic Economic Consultants (CHEC), a nonprofit forestry consulting firm. O'Toole explicitly asserts that it is a common human condition to act according to monetary incentives. Therefore, he suggests it should not be surprising that the Forest Service is first and foremost a budget maximizer. O'Toole insists the only way to modify this behavior is to change the incentives and, by definition, the economic paradigm under which the Forest Service operates. His recommendation is to "marketize" the Forest Service; that is, while the agency would remain a publicly owned institution, it would resemble a private sector business in many other respects, although special treatment is suggested for such areas as wilderness and threatened and endangered species. The agency would be divorced from congressional appropriations and dependent on revenues resulting from satisfying the multiresource public demands at fair market value prices. Furthermore, the system and program would be decentralized. O'Toole argues that this could be accomplished with a single legislative action and that the public would benefit in terms of tax savings, environmental quality, and the satisfaction of all its resource demands.

Public Policy Research Organizations

The Office of Technology Assessment (OTA), the research branch of Congress, prepared a report (U.S. Congress 1987) on the loss of earth's biological diversity and the policy options for addressing this issue. An examination of the role of planning and management on the National Forest System is included in this assessment of technologies for maintaining biological diversity in the United States and worldwide. The professional experience and knowledge of biological, physical, and social scientists from the public and private sectors were utilized through technical work groups, grassroots workshops, and commissioned papers in the development of this study. A review of the scientific literature also provided input. OTA concludes that "a comprehensive approach is needed to arrest the loss of biological diversity" and "current technologies are insufficient to prevent further erosion of biological resources." The report also concludes that deficiencies exist in the areas of public awareness and understanding, funding, personnel, and databases.

OTA asserts that a comprehensive approach requires the maintenance of biological diversity as an "explicit" objective. However, "No federal law specifically mandates the maintenance of biological diversity...as a national goal." A distinction is drawn between technologies to maintain diversity at the "ecosystem" level—the level required under a comprehensive approach as defined by OTA—and the "species management" based technologies used by the Forest Service and other agencies for maintaining biological diversity. Another major criticism focuses on the perceived failure of federal agencies to conduct the "site surveys" OTA considers necessary for planning for diversity at the ecosystem level.

Major recommendations include (1) amending legislation to make maintenance of biological diversity an "explicit" goal of federal agencies; (2) focusing diversity research on technology development and expanding its

scope beyond particular populations or species and economically important organisms; and (3) consolidating all existing and future data on the status and trends of biological diversity.

In a paper prepared for presentation at a conference concerning critical policy issues in U.S. forestry, Resources for the Future (RFF) scientists John V. Krutilla, Michael D. Bowes, and Elizabeth A. Wilman (1983) evaluate the performance of Forest Service planning to date. Resources for the Future, Inc., is a nonprofit organization working to advance research and education in the development, conservation, and use of natural resources, including the quality of the environment. These scientists interpret the intent of NFMA as a mandate to manage the National Forest System lands as an "economic asset" with an objective function of maximizing net social benefits; these benefits would be measured in monetary terms and forest management would be subject to specified constraints relating to certain nonmarket resource outputs and services required under multiple-use legislation. The authors view the regulations as being consistent with these economic efficiency and multiple-use constraint criteria. Furthermore, after reviewing numerous completed forest plans, they conclude that the procedures used in plan development also are consistent with both the legislative intent and regulatory acknowledgment of this intent. They caution, however, that their review provides only "indirect" evidence of compliance with intent. While the requisite overall economic approach could be confirmed, judging the quality of the data representing costs and benefits, the acceptability of constraint levels, and the accuracy of *all* functional relationships is regarded as being beyond reviewer competence when considered in terms of original intent.

Ignoring questions of intent, Krutilla, Bowes, and Wilman identify opportunities for improvements in the procedures and techniques used to define the forest production and demand functions. They present alternative approaches that reflect basic research accomplishments by both Forest Service scientists and others working in the areas of management science and economics. On the supply side, they suggest an iterative approach utilizing simulation modeling in concert with the sensitivity analysis capabilities of linear programming techniques to address the problem of selecting a set of prescriptions representative of an optimal land allocation pattern. They assert that the demand side should receive the highest priority for further research because the theory is less developed and the problem more complex. They cite developments in hedonic/travel cost models and the contingent valuation method as promising starting points.

Regarding the so-called joint cost allocation problem, the authors argue that costing prescriptions rather than outputs makes this a "false" issue. Finally, the critical importance of the budgeting/appropriations process to achieving the goals of forest planning is emphasized. Krutilla, Bowes, and Wilman argue for a more definitive analytical link between the range of alternative prescriptions and plans and possible budget levels. Specifically, the planning process on each forest should result in the development of a wide range of alternative prescriptions and plans representing a diverse mix of practices and outputs for any given budget level. In general, the view of these RFF analysts is that the planning process as it is presently structured is working well and, with the necessary research, its value for resource management should continue to increase.

Charles E. Hewett (1982) discusses the need to "identify new opportunities and concrete initiatives that can be undertaken to improve the effectiveness of the RPA process." Hewitt is the director of the program in forest resource policy at Dartmouth College's Resource Policy Center. In this capacity he has acted as a principal organizer of the annual Dartmouth Symposium on Renewable Resources.

Hewitt incorporates the recommendations of the working groups of the 1980 Symposium into a set of "action priorities" for improving the effectiveness of RPA activities. These priorities are classified under three major headings:

1. Improving the effectiveness of the RPA in the decisionmaking process
2. Achieving consensus and compromise
3. Improving issue recognition and assessment in the RPA.

The priorities under the first heading involve the assessment of national social, economic, and environmental consequences of alternative policy approaches to critical natural resource issues and the need to frequently and concisely present the results of these assessments to policy makers. The priorities under the second heading involve the identification and emphasis of the common goals of diverse interest groups in the RPA process and the building of coalitions of support to replace present approaches that most often result in damaging debate. The last set of priorities deals with the enhancement of the ability within RPA to recognize and analyze new issues.

Adela Backiel (1987) takes a broader view than Johnson and Sessions (1987)(reviewed below) of the limitations of the Forest Service planning process in addressing the below-cost timber sale (BCTS) issue. Backiel is an analyst in natural resources policy at the Congressional Research Service, Library of Congress, Washington, D.C. She concludes that the technical planning procedures in the planning process will be useless in solving the BCTS problem unless certain basic data and budgeting questions are addressed first.

Academia

In a paper prepared as part of a public information and education project conducted by the Conservation Foundation, Sally K. Fairfax (1981), then assistant professor in the College of Natural Resources at the University of California in Berkeley, predicts that "major adverse change" in the Forest Service will result from the RPA/NFMA laws.

While Fairfax focuses on specific principles and procedures of the NFMA planning process and describes their impacts on the Forest Service as an institution, an underlying theme of her paper is that intervention from higher governmental sources is reducing the effectiveness of the agency. Historically, the Forest Service is viewed by the author as being "uniquely successful at managing and protecting the forests." In referring to the cumulative effects of the environmental legislation passed over the past three decades on this historical performance, Fairfax states, "The tradition of land stewardship, if indeed it survived the 1950s and 1960s, may have died in the 1970s."

As for the NFMA planning procedures, Fairfax argues they are unworkable and would result in plans that would be useless for any meaningful management of resources on the ground. Fairfax states, "If the process... results in substantively 'good' decisions, it is a happy coincidence." The rationale for these assertions is the premise that Forest Service personnel are now forced to "focus their efforts on managing a process and will manage the land only as a secondary or derived activity." In her view, the initiative of experienced land managers for making technical decisions has been transferred to lawyers, computer specialists, economists, and special interest groups—the land managers' time and efforts are now taken up by insuring correct procedures, gathering data, and acting as "brokers" to negotiate compromise among special interest groups. Fairfax charges that decisions on the ground will now be dictated by the results of a staff analysis negotiated with special interest groups. She concludes that much of the adverse change brought on the Forest Service by NFMA is the result of a change in direction from decentralized to centralized decisionmaking.

Richard W. Behan (1981, 1985), dean of the School of Forestry at Northern Arizona University in Flagstaff, advocates the repeal of RPA/NFMA. While Behan has high praise for the motives and the work of both professionals and interest groups who developed NFMA and the planning process, he suggests that in doing their particular jobs nobody anticipated the fundamental flaw of the final aggregate product. In his opinion, the flaw is that the plans are mandated by *law*. Behan goes on to explain that this law mandates a rational, completely objective planning process. However, such perfection is impossible in the real world. Because an "imperfect plan is an illegal plan" the inevitable result will be "forest management by court decisions, instead of the considered judgment of professional land managers."

Behan asserts that the essential and central aspect of efficient and correct resource management decisionmaking is the professional and experienced judgment of the land manager. He argues that this attribute will be neutralized or displaced completely by the statutory requirements for managers to concentrate on documentation, consistency, and correct procedures—even in cases where legal challenges and opinions do not enter the process.

Behan states that another related reason to repeal RPA/NFMA is the cost factor. He asserts that the planning process itself is not analyzed systematically in cost-benefit terms. Finally, Behan claims that while one of the major intents of Congress in passing RPA/NFMA was to insure adequate funding, the planning process has had minimal effect on Forest Service appropriations.

While Behan views RPA/NFMA as a costly mistake, he does recognize the need for a reshaping of public forest management. He is encouraged that three ingredients essential to a successful reform are currently in place. First, he notes the traditional Forest Service "can-do" attitude. Second, he observes a newly emerging sophistication on the part of the Forest Service with respect to integrating public concerns into land management decisions. And third, he sees improvements on the part of special interest groups with respect to "their abilities to speak intelligently and even (sometimes anyway) objectively...." These three factors, in his view, provide a foundation for a flexible land management planning process based on professional experience and judgment and the resolution of controversies through bargaining, negotiation, and mediation unimpeded by statutory regulation.

Gerald M. Allen and Ernest M. Gould (1986) draw a distinction between "complex" and "wicked" problems with respect to public forests. Allen is a professor in the Department of Forestry at Humboldt State University in Arcata, Calif. Gould is assistant director and forest economist at the Harvard Forest in Petersham, Mass. Allen and Gould define "complex" problems in forestry as those well-suited to a systems analysis solution approach. Such problems are common in day-to-day tactical operations and are characterized as having either a right or wrong solution. In contrast, "wicked" problems never have a well-defined solution because of an inherent political component. Such problems do not lend themselves well to a systematic method of solution.

Allen and Gould assert that in formulating the rules for implementing the planning process mandated by NFMA, the Forest Service is "confusing complexity with wickedness." In their view, strategic planning is a "wicked" problem that cannot be dealt with successfully in a comprehensive, rational approach. They argue it is time to reevaluate the directives of NFMA and investigate alternative planning procedures. Although they present no specific recommendations, Allen and Gould emphasize incremental planning and the talents of forest managers as being central to any alternative approaches.

Dennis E. Teeguarden (1987), professor of forestry economics in the Department of Forestry and Resource Management at the University of California in Berkeley, discusses economic efficiency criteria with respect to congressional intent and practical use in national forest planning. Teeguarden acknowledges the clear intent of Congress that economic efficiency criteria be used in the development and evaluation of alternative forest plans and lauds their "wise" decision to be ambiguous as to the weight to be given this tool in the Forest Service planning process. He asserts that this ambiguity allows the Forest Service discretion in the use of economic efficiency criteria to reflect empirical limitations unique to forest

resource planning as well as the limitations associated with benefit-cost analysis. Furthermore, Teeguarden argues that public forest planning is essentially a political decisionmaking process in which distributional or equity criteria also play a major role.

Teeguarden describes the functional roles of benefit-cost analysis in the Forest Service planning process. These include (1) to provide and integrate quantifiable economic information; (2) to help mitigate extravagant claims by interest groups and promote compromise; and (3) to approximate economically efficient management activities and programs. Teeguarden recommends continued research to facilitate the application of these functions.

In response to doubts raised about the ability of NFMA to improve the rationality in the Forest Service planning process, Paul Mohai (1987) addresses the issue with an analytical and empirical approach. Mohai is an assistant professor in the School of Natural Resources at the University of Michigan in Ann Arbor. Mohai framed his analysis in the context of two questions: (1) " ...if not rationality, what factors influence agency decisionmaking?" and (2) "...what advantage can planning be expected to achieve?" His approach to answering these questions consists of three distinct elements: a theoretical analysis based on the alternative models of government decisionmaking developed by Graham Allison; a review of the literature concerning Forest Service decisionmaking; and empirical results from the Forest Service's Second Roadless Area Review and Evaluation (RARE II). According to Mohai, evidence from these elements does not support the hypothesis that rational processes significantly influence Forest Service decisionmaking. Instead, institutional factors, such as tradition and resistance to change, and political considerations prove to be more significant. Furthermore, he indicates that changes instituted through the planning process are incremental in nature.

Mohai asserts, in answer to the second question, that legitimizing the "rules of the game" may be the most significant effect of RPA/NFMA. He argues that this legitimizing provides each actor in the planning process some measure of predictability and control, and this leads to a greater potential for compromise.

K. Norman Johnson and John Sessions (1987) address the ability of the Forest Service planning process to resolve the below-cost timber sales issue. Johnson is an associate professor of forest management and Sessions, a professor of forest engineering, at Oregon State University in Corvallis. Johnson and Sessions base their analysis on two fundamental tenets: (1) the goal of public forest management—the maximization of *net public benefits* (NPB)—can only be achieved through a level of planning that encompasses the whole forest; and (2) below-cost timber sales (BCTS) are defined in terms of a negative NPB. In assessing the ability of forest planning to at least identify BCTSs, the authors focus on two sub-issues: the determination of land suitable for timber production; and the examination of individual sales or areas in isolation from forest level planning. Johnson and Sessions suggest that much of the controversy surrounding BCTSs results from a misunderstanding concerning the designation of "suitable" lands. The "economic suitability" of timber lands is determined in the FORPLAN analysis for each alternative. The land base that most efficiently meets the objectives and constraints of each alternative is declared "suitable." The objective is normally the maximization of present net value (PNV) while constraints are required as the only way to meet qualitative criteria. Within this analytical framework, it is possible for lands that have a negative PNV to be included in the suitable timber base if, in also considering the constraints, their beneficial impact on the forest-wide solution is positive. The authors see nothing inherently wrong in such an outcome and reject the notion that the BCTS issue should focus on a cash flow analysis with respect to PNV. They demonstrate how such a focus would compromise the ability of forest planning to identify the most cost-effective strategy for achieving forest-wide goals. Johnson and Sessions assert that forest level planning has the best potential as the vehicle for addressing the BCTS issue because it is theoretically designed to define the sales that most cost-effectively meet the objectives and constraints of the alternatives.

Charles F. Wilkinson and H. Michael Anderson (1987) have published one of the most exhaustive reviews of RPA as amended by NFMA to date. Wilkinson is a professor of law at the University of Colorado in Boulder and Anderson is a forest planning specialist with the Wilderness Society. The focus of this review by Wilkinson and Anderson is the interpretation of RPA/NFMA as Congress intended it. The authors document their review in great detail, analyze the legislative history behind the law, and delve into the statutes, regulations, manual provisions, draft plans, interdisciplinary committee proceedings, administrative reviews, and judicial interpretations. They also refer to numerous sources in the general literature on forest planning. In the process they draw comparisons between their interpretations and actual implementation.

An integral part of their analysis involves a review of the historic events that led to RPA and NFMA. The authors suggest the primary purpose of RPA was to improve funding but its most significant effect was its impact on the traditional autonomy of the Forest Service. They describe NFMA as a referendum on Forest Service timber practices that resulted for the first time in substantial restrictions on this autonomy. National plans were now required to be considered in local forest level planning decisions. This produced what Wilkinson and Anderson call "an uneasy compromise between... top-down and bottom-up" planning. However, they conclude that the ambiguous treatment by Congress of most of the issues addressed in the statutes has left the Forest Service with a considerable amount of its prior discretion. For example, Congress did not amend the section of the Organic Act that granted the Forest Service its basic authority to "regulate...occupancy and use...of lands and resources within the national forests."

Throughout the book, Wilkinson and Anderson compare the intent behind the statutes with the manner in which the Forest Service performs its delegated authority

and they cite numerous contrasts. For example, they point out that the suitability provisions in the NFMA regulations appear to be less restrictive than the requirements of NFMA itself. The authors also acknowledge the criticism of others with regard to the complexity, expense, and drain on human resources inherent in the NFMA planning process. More significantly, they contend a commodity bias still exists in the Forest Service. However, they state,

> ...we have come to appreciate the essential wisdom of the NFMA planning process. It creates valuable inventories, offers the potential of engaging the public and diverse disciplines, and holds out the promise of creating ordered and principled decisionmaking. Granted, these benefits will accrue over time, not instantly, and they will come at some cost, but we believe that the basic goals and process of the NFMA will prove out.

USDA Forest Service

Con H. Schallau and Richard M. Alston (1987) comment on the community stability issue in national forest planning. Schallau is a research economist with the USDA Forest Service, Pacific Northwest Research Station in Corvallis, Oregon. Alston is a professor of economics at Weber State College in Ogden, Utah. Although neither RPA or NFMA directly address the issue of community stability, and theoretical support of the link between community stability and sustained yield timber policies is lacking, Schallau and Alston argue that this issue has a legitimate role in the Forest Service planning process. They base this assertion primarily on the history of Forest Service consideration of community stability and an interpretation of the concepts of "net public benefits" and "planning criteria" from NFMA and the regulations that would "implicitly allow" the consideration of community stability. Schallau and Alston concede that community stability should not be used to justify high levels of timber sales that cannot be justified for biological or economic reasons. However, the issue needs to be considered with respect to questions of equity—especially in cases where economic dislocation may result from Forest Service practices or programs. The authors argue that those affected should at least be informed.

In 1982 the Forest Service cosponsored a workshop "to identify the current state of information and the future needs to implement the NFMA provision for diversity on national forests...." The technical papers presented at this meeting (Cooley and Cooley 1984) reveal a wide range in methodologies utilized to incorporate diversity into the Forest Service planning process. This reflects both the ambiguity of congressional intent and the limited guidance from the Washington Office. While the reasons most often cited for incorporating diversity into the planning process varied, it was generally agreed that diversity was an important element. Some of the most substantive conclusions and recommendations resulting from the workshop are reproduced here, categorized as either policy issues or procedural and technical issues.

Policy Issues:

1. Current direction in policy, regulations and planning guidance is adequate.
2. Diversity should be viewed as an effect, a consequence, of management, and not an end of management itself.
3. While the formalization of management practices in planning for diversity was considered an important goal, no consensus was reached concerning a way to institutionalize this concept.
4. There exists a need for clearer public perception of diversity and better methods for measuring this perception.
5. The preservation of ecosystems that are not represented or are underrepresented by current preservation strategies and the minimum area requirements of certain species will both require interagency cooperation.
6. More research is needed to improve methodologies for integrating diversity into the planning process.

Procedural Issues:

1. While it was generally agreed that the consideration of diversity in the planning process is adequate, consensus was elusive as to diversity measurement and temporal standards.
2. The forest planning documents need to more clearly display the depth of the analysis carried out.
3. Cultural and archeological resources need additional consideration.

In 1984 the Forest Service held a workshop to consider the changes in forest land inventory data needs brought about by the RPA/NFMA legislation and anticipated budgetary constraints. A primary objective of this workshop (Lund 1984) was to review the draft Forest Service manual concerning inventories used for developing forest plans, RPA Assessments, and Programs and to solicit additional recommendations from the Regions. Critical issues identified and addressed were resource inventory-planning relationships and information needs; design criteria; inventory direction, coordination, and responsibility; inventory budgeting; and data processing support.

In 1982 the Forest Service conducted a workshop on "Social Impact Analysis in the Forest Service" for the benefit of Forest Service social scientists. The objectives of this workshop were to review relevant sections of the Forest Service manual and explore ways to improve the practice of social impact analysis (SIA) in the Forest Service. The papers of Susan Giannettino (1982), Jean Schwabe (1982), and Gerald Williams (1982) represent the unique approaches to SIA that the management situation on their respective forests require. Giannettino stresses the importance of having a social scientist on the core planning team. She asserts that planning and management objectives should reflect not only biological and physical considerations, but also social acceptabil-

ity. In her view, core team membership is the surest way to achieve this. Schwabe describes SIA from the perspective of an urban forest where significant social impacts and effects have their origins beyond the forest boundaries and affect the forest. Conversely, Williams describes his perspective of the situation on a heavily timbered and harvested forest where the social impacts of concern are those generated by forest activities and programs that have social consequences for local and national publics.

David C. Iverson and Richard M. Alston (1986) trace the development of the analytical tools utilized by the Forest Service in response to land management planning requirements that have shifted the emphasis from functional to integrated interdisciplinary analysis. Iverson is the regional economist for the Intermountain Region of the Forest Service. Alston is a professor of economics at Weber State College in Ogden, Utah. The focus of this review is on the authors' critical evaluation of the latest generation of models. Iverson and Alston describe the development of FORPLAN (actually FORPLAN Version 1) in terms of its capability and the NFMA-mandated requirement for integrated land-use planning. They view the major accomplishment of FORPLAN Version 1 to be its ability to trace multiple resource activities through time. However, they discuss problems with respect to model size and the generation of unreasonable timing choices. The authors suggest that while creative analysts could mitigate these problems, a more intractable problem was a perceived timber bias underlying the FORPLAN system. This perceived bias arose because the system's emphasis was on long-term timber harvest scheduling, while many planners were becoming more interested in specific multiresource allocation questions. According to the authors, these concerns and others led to the development of FORPLAN Version 2. A major advance in this system is the flexibility it affords in specifying activities and outputs across space and time. In Iverson and Alston's view, this advance extends the usefulness of modeling to all resources.

While Iverson and Alston believed a specific evaluation of FORPLAN Version 2 would have been premature, they do offer a critique of mathematical programming techniques in general. First, they remind the reader that linear models cannot handle nonlinear problems very well. Second, the potential for complexity is inherent in linear programming models. Finally, the authors caution, "Mathematical programming in general, and linear programming in particular, is most useful in understanding the nature of the problem, not in providing numbers representing the 'answer' to a problem." Iverson and Alston conclude that the benefits of modeling exceed the costs. They suggest the key to success is intelligent problem identification and model specification.

In a later paper, Alston and Iverson (1987) address the strengths and weaknesses of FORPLAN Version 2 more directly by applying the criteria Chappelle et al. (1976) utilized in a "devastating" critique of earlier forest planning models (Timber RAM and MUSYC). While their conclusions regarding the strengths of FORPLAN Version 2 are similar to those in their earlier paper, they are more explicit concerning the weaknesses of the model. They focus on the pitfalls inherent in the areas of problem identification and the model's "analytical flexibility." Of particular concern are the substitution of "presumed facts" for professional judgment and the misuse or abuse of shadow price analysis. Underlying these concerns is the authors' conclusion that FORPLAN Version 2 is not designed to identify problems, nor is it able to "consider all linkages with the rest of the world simultaneously." Complicating these weaknesses is the computational complexity of the model and the uncertainty of technical assistance from a central agency support unit.

In 1986, the Forest Service sponsored two meetings pertaining to the Forest Planning system FORPLAN. The first was a national workshop that explored the lessons learned in the agency through the use of FORPLAN; the participants at this workshop were almost exclusively Forest Service personnel. The second was a symposium whose theme was an evaluation of FORPLAN; unlike the workshop, participants included numerous nonagency experts and members of interest groups, in addition to agency personnel. These external experts played the lead role in the evaluation, with background and supporting information being provided by agency experts. Proceedings of both of these meetings have been published (Bailey 1986, Hoekstra et al. 1987). Both proceedings contain useful information and recommendations on a number of subjects pertaining to National Forest planning, FORPLAN, and the agency's planning process. Kent et al. (1988) summarize these two proceedings and conclude,

> Perhaps the most interesting conclusion to draw from this review is the consistency with which certain research problems were identified. This is especially interesting when the diversity of participants in the two meetings is considered. We group these problems into one of two categories, basic and applied, and then briefly identify some of the more important ones in each category. Important problems in the first category include:
>
> 1. A more complete characterization of the agency's overall planning process needs to be developed.
> 2. Once item 1 is completed, the role of forest planning and the role of analysis can be more clearly defined.
> 3. With the planning process and the role of forest planning characterized, attention can be turned to an identification of planning strategies (i.e., rational comprehensive vs. hierarchical) and the role of analysis in planning.
> 4. The choice of analysis tools must then be considered and new systems must be developed or existing ones modified as appropriate. Necessary linkages between systems must also be identified and developed. This work must take into consideration the need to better incorporate nontimber resources, spatial concerns, and uncertainty in planning analysis. Throughout all of these investigations, the need to make planning and

analysis understandable to interested parties both in and outside the agency must be kept in mind. Necessary linkages between different levels of planning must be developed and at all times the underlying goal of improving management and decisionmaking through planning must be kept in mind.

Among the more important applied problems are:

1. Critical data needs for planning and analysis must be identified and satisfied.
2. Our understanding both of how to implement plans and how to utilize the results of implementation to facilitate the next round of planning must be improved.
3. A better understanding of the implications of budget levels on planning must be developed.

While this paper has focused on problems with the first round of planning, it would be remiss not to point out that much has been accomplished. It is also clear that the problems surfaced during the two meetings are difficult and will be challenging to address. As is often the case, the difficult problems are the last to be resolved.

State Resource Agencies

William C. Unkel (1985), a natural resource biologist with the California Department of Fish and Game, cites specific sections of the legislation, regulations, and Forest Service manuals; interprets their language; and concludes that these planning process components are consistent with natural diversity goals. Unkel asserts, however, that the Forest Service will need assistance in transforming intent into both forest plan results and outcomes on the ground because (1) many of the diversity provisions of NFMA and the regulations are "superficially" prescriptive; (2) there is no precedent for a Forest Service interpretation of diversity; and (3) the meaning of diversity is also scientifically ambiguous. He suggests that state and private natural heritage programs are often the source of the best available information on natural diversity and could best serve in this consulting role. Unkel also explains how the diversity mandate as it is interpreted in this article is legally enforceable through the "reasonableness" test.

Legal Community

F. Kaid Benfield (1987), senior attorney with the National Resources Defense Council, examined Forest Service planning process compliance with the standards of the Administrative Procedures Act (APA) and the National Environmental Policy Act (NEPA). He addressed two specific issues: (1) the adequacy of the decisionmaking record under RPA; and (2) the sufficiency of the range of alternatives under NEPA. Case studies involving two forest plans reveal inconsistencies between planning units and general shortcomings with respect to both acts. These shortcomings involve planning decisions that were not adequately supported or verified in the planning records, an unresponsiveness to public input, and an insufficient range of management options. Benfield concludes that the present Forest Service approach is legally vulnerable. He suggests that the appeal process be used to identify and correct mistakes and make planning actions between separate administrative units more consistent in order to avoid litigation.

W. Hugh O'Riordan and Scott W. Horngren (1987) claim that the Minimum Management Requirements (MMRs) in the Forest Service planning process violate the NFMA. O'Riordan is a partner in the law firm of Lindsay, Hart, Neil, Weigler. Horngren is a timber supply specialist for the Western Forest Industries Association and a law student at Northwestern School of Law at Lewis and Clark College. Throughout their critique of the MMRs in the planning process, O'Riordan and Horngren cite and interpret specific sections of the legislation, regulations, and internal guidelines and directives. They charge that the Forest Service considers the MMRs as "inflexible legal standards over which there is no discretion" and that the agency applies them as a common constraint across all forest plans and alternatives. Furthermore, O'Riordan and Horngren assert that the Forest Service established these protection rules without public participation, interdisciplinary analysis, or integrated planning, which is in violation of the process mandated under NFMA. They argue that the term "minimum management requirement" is not even found in NFMA. The authors conclude that while the Forest Service does have the discretionary authority to promulgate MMRs, the present ones are illegal, and any plan constrained by them must be revised or will be subject to legal challenge. O'Riordan and Horngren make several recommendations. They suggest that the Forest Service develop a new set of MMRs through the public participation, interdisciplinary analysis, and integrated planning requirements of APA and NFMA. They also assert that protection constraints should vary among alternatives. Finally, they believe the RPA Program should include resource protection goals as well as those for resource outputs.

James F. Morrison (1987) (a lawyer with the USDA Forest Service) asserts that below-cost timber sales (BCTS) have resulted from the failure of the Forest Service to effectively transform the original intent of Congress with respect to the determination of suitable timber lands as codified in Section 6(k) of the NFMA into the regulations and guidelines. Morrison interprets the economic efficiency provisions of Section 6(k) as requiring timber production to be profitable. That is, the present net value (PNV) of any harvest activity on a particular land parcel must be positive in order for that land to be considered "suitable" for timber production. He cites provisions of the legislation, congressional debate, and other sources to develop this argument. He suggests that the primary culprit in the BCTS issue is the nondeclining even flow constraint. In his view, the principal motivation behind harvest flow constraints is community stability. This prompts Morrison to question the legali-

ty of these constraints because community stability is not defined in NFMA as a multiple use objective. Morrison views Forest Service planning as an evolutionary process that should be responsive to new information and opportunities. He argues that BCTSs represent a significant, unanticipated result of the process that should evoke a reevaluation of goals and procedures. His recommendations include reducing harvest levels to coincide with those sustainable from a profitable land base and a reevaluation of harvest flow objectives.

Conclusions

While the critiques reviewed in this paper are taken from a representative cross section of Forest Service publics, the reader cannot assume that all points of view or even all issues of concern are explicitly revealed. Such an outcome would require an exhaustive approach beyond the scope and feasibility of this literature review. However, this review does provide insights into which planning process aspects and issues elicit the greatest interest and which areas elicit the most agreement or disagreement. Rather than finding consensus, this review highlights the diversity of individuals and groups interested in the Forest Service planning process and their points of view. Consensus is limited to the conclusions that the planning process is very complex and costly and that it contains a significant political component. Some generalized findings from this review include the following:

1. Positions taken by different types of groups are sometimes surprisingly compatible.
2. Contrasting points of view are sometimes held by similar groups.
3. The differences between disparate groups can be extreme and seemingly irreconcilable.
4. Positions within the same group or between groups with similar interests display the most agreement.
5. Conflicting conclusions are often drawn from similar, seemingly objective analyses.
6. Similar conclusions are sometimes derived based on different rationales.

Perhaps the most useful revelation of this review involves the identification of land management planning on the National Forest System as essentially a political process. This has been a persistent theme in the critiques of the USDA Forest Service land management planning process since RPA and NFMA became law. In one of the first organized critiques of RPA/NFMA planning, Parry (1983) views the consideration of methodological issues as inseparable from discussion of the political environment. In a recent paper that examined the role of distributive and allocative efficiency measures in the RPA/NFMA planning process, Alston and Iverson (1988) conclude that in the final analysis "the focus must be on mutual accommodation, compromise, political negotiation, and qualitative decision processes."[6]

Despite this emphasis on political feasibility, it appears that political considerations may not be adequately specified in the planning process. While a case can be made that the requirements for public involvement and the identification of public issues were instituted to address the political component of planning, Dale J. Blahna and Susan Yonts-Shepard (1987) suggest that a 1986 Forest Service study of the use of public involvement in forest planning shows that "while the forests conducted formal issue identification procedures, often the issues as identified were not useful for developing most Forest Plans." They go on to assert,

> The major problem with...[Forest Service] comment analysis methods was that information that was important to planning was lost in the process....At each step, the Forests have tended to react to the public issues rather than working proactively to obtain consensus before they escalated into full-fledged conflicts.

Blahna and Yonts-Shepard cite the large number of current and expected appeals as evidence of this conflict and of the ineffectiveness of the Forest Service in linking public issues and the analysis process in developing planning alternatives. Finally, the authors recommend an "issue management" approach to public involvement that would require a more detailed specification and description of the issues incorporating "the criteria of opposing parties" and the application of conflict resolution and integrative problem-solving techniques and skills.

In a similar analysis, Julia Wondolleck (1988a, 1988b) further develops the argument that the current public involvement process promotes conflict rather than compromise. Wondolleck outlines in detail conflict management concepts she believes could result in successful decisionmaking in the sense that, "Whereas it is unlikely that there will ever be technically discernable 'correct' solutions to today's forest management tradeoffs, there can be solutions that will be accepted and supported by affected interests." Wondolleck reinforces her recommendations with documented examples of successful Forest Service experimentation with dispute resolution techniques.

These results suggest that the efforts of a Forest Service critique might best be directed at examining the diversity in publics, issues, and views involved in the planning process in the context of the "political feasibility" of the decisionmaking process.[7] The question to be investigated would then be, How can political considerations be integrated into the technical and procedural aspects of the planning process in a way that addresses the problems arising from the inherent diversity of values represented in the planning issues and criticisms? An examination of the potential role of conflict resolution concepts could be a point of departure in such an approach.

[6] *Alston, Richard M.; Iverson, David C. 1988. An economic interpretation of net public benefits in forestry. In process.*

[7] *Attempting to define a consensus based on a terse treatment of the currently available critiques could suffer from the same kind of loss of information that Blahna and Yonts-Shepard describe in their critique of the current Forest Service comment analysis methods.*

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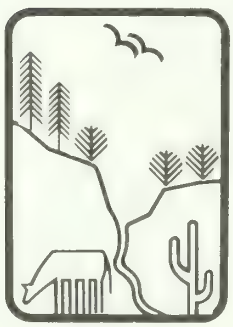
U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains



Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-171**

Ninth Great Plains Wildlife Damage Control Workshop Proceedings

April 17-20, 1989
Fort Collins, Colorado

Great Plains Agricultural Council Publication 127

Bjugstad, Ardell J.; Uresk, Daniel W.; Hamre, R.H., technical coordinators. 1989. Ninth Great Plains Wildlife Damage Control Workshop Proceedings. General Technical Report RM-171. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 181 p. [Also listed as Great Plains Agricultural Council Publication 127.]

Abstract

These proceedings consist of 43 presented papers on control of damage caused by many different animals. After an "overview" session, papers were presented in sessions titled: Carnivores, Urban, Big Game, Birds, and Rodents and Lagomorphs.

Keywords: Prairie dogs, coyotes, rodents, bird repellents, predacides, rodenticides.

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USDA Forest Service
General Technical Report RM-171

July 1989

Ninth Great Plains Wildlife Damage Control Workshop Proceedings

April 17-20, 1989
Fort Collins, Colorado

Technical Coordinators:
Ardell J. Bjugstad, Daniel W. Uresk, R. H. Hamre
Rocky Mountain Forest and Range Experiment Station

Sponsor:
Great Plains Agricultural Council, Wildlife Resources Committee

In cooperation with:
USDA Forest Service
USDA Animal and Plant Health Inspection Service
Colorado State University
Colorado Division of Wildlife
Colorado Department of Agriculture
Wyoming Game and Fish Department

Great Plains Agricultural Council Publication 127

Preface

The professional field of animal damage control has evolved over the years into a complex and diverse activity. It continues to be a very necessary part of the wildlife management scheme. However, it has become increasingly important to include the public and their impressions and attitudes in all phases of planning and implementation. Communication, public involvement and a sensitivity to people and wildlife are now required tools of the trade.

In his keynote address Jack Berryman told us of the necessity to be aware of the attitudes of the public of all phases in vertebrate pest management. We must not be solely defensive. The public must be informed about what is being done, why it is being done, and how all humaneness possible is included in the how it is being done.

The eventual consequences of legislation banning steel leg-hold traps is serious. Such legislation is proliferating and has passed in some states. Such actions require our full professional attention.

This workshop brought together about 200 professionals who shared their experiences, thoughts and projections into the future. Many of the papers presented included a dimension involving the attitudes of various publics plus the influence of those attitudes on the work being done. Only by being keenly aware of the importance of the public in animal damage control programs and by professionally sharing ideas and experiences on how best to conduct good ADC programs will the animal damage control component of wildlife management continue to thrive.

People and wildlife can live together in harmony with proper management and attitudes. Vertebrate pest control methods are evolving well, however both professionals and the public must strive for understanding, balance and harmony.

While many persons contributed to the success of this workshop special thanks are due Gerri Siverts, CSU Extension secretary and the CSU Wildlife students, Chuck Anderson, Rick Gardner, Ron Thomas, Mike Warner, and Jeff Williams, who assisted with audio visual needs.

Although they are listed in these Proceedings, the session moderators, the planning committee, financial contributors and various supporting agencies all deserve special thanks.

The field trip was to Rocky Mountain National Park. Dave Stevens, wildlife biologist, U.S. Park Service, assisted by Rick Spowart, District Wildlife Manager, Colorado Division of Wildlife, made the trip both enjoyable and educational. Thanks to both of them.

We look forward to seeing all of you again in Lincoln, Nebraska in 1991.

Robert S. Cook
Wildlife Committee, GPAC and
Conference Co-chair

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Workshop Summary[1]

William F. Andelt[2]

The Ninth Great Plains Wildlife Damage Control Workshop was attended by 195 registered participants. Participants arrived from at least 20 states and 2 Canadian provinces. A total of 54 papers were presented at the workshop. Seventeen exhibitors provided commercial displays. The workshop concluded with a field trip to Rocky Mountain National Park where wildlife management in the park and elk damage to aspen trees were discussed.

A large diversity of occupations were represented by workshop participants including ranchers, professional pest control operators, extension wildlife specialists, fish and game agency personnel, university and agency researchers, administrators, and others. Participants were very interested in prevention and control of wildlife damage. However, they also were interested in song birds, endangered species, and wildlife enhancement in general.

A great deal of information was exchanged at the workshop. Jack Berryman encouraged us to publish and share our knowledge about wildlife damage control. Bobby Acord stressed that we should measure the success of an animal damage control program by the amount that damage is reduced and not by the number of animals that are removed. Mike Leroux and Ed Hansen, both ranchers, indicated that ranchers like to have wildlife on their lands but ranchers want to be compensated for allowing a large number of wildlife that cause damage to remain on their lands. They also indicated that wildlife agency animal damage control programs are too complex and that additional dialogue is necessary to improve rapport between wildlife agencies and landowners.

The workshop emphasized papers on carnivores, big game, birds, urban wildlife, and rodents and lagomorphs. Agency programs and solutions to wildlife damage problems were discussed. Evaluations of several innovative animal damage control techniques such as the use of monofilament lines for reducing bird activity in citrus trees and around bird feeders as well as the use of anthranilates for repelling birds from cherries and livestock feed were discussed.

Robert Schmidt presented the concerns and views of individuals interested in animal rights and animal welfare. Animal welfare interests are primarily concerned about pain and suffering in animals. He emphasized the use of effective animal damage control techniques that result in the least adverse impacts on problem animals. Dale Shaw (Dr. Martin Windsor), in a thought provoking discussion, emphasized the need for hunters to display appropriate behavior when pursuing their sport.

A diversity of views on the effectiveness of some animal damage control techniques, especially livestock guardian dogs, were presented. Presentations of opposing views are beneficial because they frequently elicit thought, discussion, and additional ideas for better ways to employ animal damage control techniques. Although it is frequently easy to criticize certain animal damage control techniques, the challenge upon us is not to criticize but rather to invent new techniques, determine how to better adapt old techniques, and to determine why other techniques do not work.

In the future, conflicts between man and wildlife will continue. Demand for wildlife damage prevention and control techniques and educational information likely will increase. Wildlife damage control professionals need to continue to evaluate animal damage control techniques and publish their findings. They need to evaluate techniques by conducting true experiments with treatments and controls; descriptive studies are not enough. In the future, wildlife damage control professionals will need to select control methods based upon their effectiveness, minimal amount of pain and suffering caused to target animals, minimal impact upon non-target species, public opinion, and lastly cost. Our roles will remain important for reducing conflicts with wildlife and retaining wildlife on our lands.

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[1]Summary of papers presented at the Ninth Great Plains Wildlife Damage Control Workshop, Apr. 17-20, 1989, Fort Collins, CO.

[2]William F. Andelt is Associate Professor and Extension Wildlife Specialist at Colorado State University, Fort Collins.

Animal Damage Control: The Challenge of the 90's[1]

Jack H. Berryman[2]

Abstract.--The talk identifies the challenges of the 90's as: to fully professionalize the policies and practice of animal damage control; to provide a responsible and acceptable level of control; to gain executive and legislative support; and to improve public acceptance. It points up a number of obstacles and identifies several steps necessary to meet the challenges.

I am really pleased to have this place on the program because I firmly believe that the 90's provide unparalleled but achievable challenges and opportunities in the field of animal damage control. But, there are also unparalleled obstacles to be surmounted.

At the outset let me state the challenges as I see them: to fully professionalize the policies and practice of animal damage control; to provide a responsible and acceptable level of control; to gain executive and legislative support; and to improve public acceptance. In short, to get animal damage control back on its feet. That is a very full plate indeed.

And, there are some very imposing obstacles to be confronted: a long period of benign agency neglect which has sometimes bordered on irresponsibility; increasing public antagonism coupled with declining constituent confidence; declining professional acceptance; and, the mounting influence of the animal rights movement.

Animal damage control is at a very pivotal point in its long and checkered history. The circumstances are right for basic advances -- if we collectively seize the opportunities that now prevail.

I feel I can be candid because of a long involvement in and with animal damage control work.

Let us pause for a moment to review the causes of some of the problems. Animal damage control was one of the early targets -- and victims -- of the so-called "environmental movement" of the late 60's and early 70's. Faced with the increasing emotional attacks of protectionist organizations, the Federal Government and some state governments waffled in their responsibility to implement and defend responsible programs. Rather, they vacillated, which only fueled the fires and added to the divisiveness. They misjudged the movement, thinking it was aimed only at animal damage control, not realizing that it was only the forerunner of a broader anti-hunting and anti-management movement. And, that it would later blossom into the animal rights crusade.

The Federal role was anything but an example of responsible leadership. Aided and abetted by EPA and CEQ, the Department of the Interior tried several tacks. One Secretary wanted Interior "out of the business" which finally resulted in eliminating many of the tools; one studied the problem for his entire tenure -- but successfully avoided decisive, responsible action; and one finally solved the problem, at least for Interior. He got rid of it by acceding to its transfer to the Department of Agriculture. More on that later.

Regrettably many wildlife professionals, especially those in administrative positions, did not cover themselves with responsible, professional glory. They found the activity too controversial. It detracted from their mission; it lacked the appeal of such issues as rare and endangered species; and they did not consider it a part of wildlife management.

With Federal apathy, professional snobbery and mounting public antagonism, some conservation organizations abandoned animal damage control and either moved to neutral or antagonistic ground.

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[1]Keynote address, Ninth Great Plains Wildlife Damage Control Workshop, Fort Collins, Colorado, April 18, 1989.

[2]Counselor Emeritus, International Association of Fish and Wildlife Agencies, Washington, D.C.

And through it all, those who suffered damage lost confidence in the agencies responsible for providing relief -- and some began to take matters into their own hands.

So much for history. It is in the past, and we must look to the future. But, we must understand the reasons for the very low ebb of the late 80's if we are to take constructive positive action to turn the tables in the 90's.

I believe that history will record that the transfer of the animal damage control activities from Interior to Agriculture was the institutional change that set the stage for constructive action. And in saying that, I point out that the International Association of Fish and Wildlife Agencies, which I represented, firmly opposed that transfer as a matter of principle.

One of Agriculture's leaders likened that action to repotting a plant. It is a good analogy. The revitalization is being reflected in improved direction, support and employee morale -- and with actual gains in a professional approach to animal damage control.

The subsequent establishment of the Secretary's Animal Damage Control Advisory Committee provided the means for involving a wide array of interests to assist in implementing a revised and responsible program. I am pleased to be a member of that Committee. With the full cooperation and support of Agriculture leaders, it is moving in a positive way to redirect the Federal role in animal damage control and to define the role of cooperating agencies and organizations. Animal damage control programs rely mainly on the 1931 Act for legislative authority. There remains an urgent need, however, for a legal or legislative clarification on the responsibility for control of waterfowl depredations. I sincerely hope that the leadership, support and direction in Agriculture and APHIS are continued by the new Administration; and, I implore support for its continuation.

Now, with the initial institutional steps taken, what can we, as individuals, do to meet the challenges of the 90's?

First, we need to take a new look at ourselves -- at the profession. Animal damage control is a fundamental part of wildlife management. It is not a separate entity; never an end in itself. The control of animals is never the objective; rather the prevention of various kinds of damage necessary to accomplish a specific management objective. It works in harmony with research, enforcement, protection and acquisition as one means of regulating animal numbers to accomplish a specific management objective. It is also necessary to this Nation's production of food and fiber and as a service to constituents in protecting communications and transportation and human and animal health. In short, it is a vital function and its practitioners are integral contributors to rational resource management -- in no sense second class citizens in the resource community.

Enough of self-examination; we have much to do.

Animal damage control must be fully professionalized. A solid data base, sound policies, improved methodology, protocols and accountability are givens and require no elaboration by me. Additionally, there are specific things that each individual can do.

The long period of harassment of animal damage control workers has caused them to draw inward, to isolate themselves, to adopt a seige or "circle the wagons" mentality. Well, the seige has been lifted and its time to become full and active partners in the professional community. It is extremely important to participate actively in the professional societies; to attend, participate and present papers at the national and regional meetings -- in a word, to come out of our shells and rejoin the professional community.

It is important that those engaged in animal damage control, whether it be in operations, extension, surveys or research, publish more widely in the professional journals and outlets. In addition to publications on the methodology of control, it is necessary to document field observations, results, the ecology of control, and related economic findings. There is need to add to the credible body of knowledge on every aspect of animal damage control. And, this should not be left exclusively to the universities or the researchers. It should also come from those actually engaged in management.

Related to all of this, there has been a welcome change in the views of many wildlife managers. Some of you may recall that following issuance of the Leopold Report in 1964, the popular view was that animal control had no role in wildlife management. Well, it has now been documented that it does have a role under some circumstances -- in the re-establishment or re--introduction of endangered species, in pheasant and waterfowl management and aquaculture. And, there has been increasing recognition of the role of control in protecting communication and transportation systems. So, there is an improved professional climate. This workshop is evidence of that change.

There is need for all of us to influence the universities that animal damage control should be included in wildlife management curricula. It is indefensible that such an important, complicated, controversial and sensitive subject is not covered adequately by formal instruction when students are acquiring the background they will need for a professional approach to resource management issues.

One of the most important first steps in securing public acceptance and increased legislative and executive agency support is to improve cooperation and relationships all across the board. In meeting with the States, the Woolgrowers, APHIS personnel and others, I detect some animosities and frictions -- some overt lack of cooperation. It is a luxury we cannot afford. The agencies of the Federal Government, the state fish and wildlife and agricultural agencies and industry cooperators are all partners in animal damage control work, by practical necessity, by agreement and by legal mandate. This means that cooperation and good working relationships are not just desirable -- they are imperative. To win support, they must stand as one. I urge all concerned to take the initiative -- to take the first step in repairing and building these relationships.

In addition to working in professional and cooperative circles, we must reach the public with accurate information on all aspects of control. We must achieve credibility with the media and utilize all forms of education, including extension, to improve public acceptance.

Obviously a major challenge of the 90's is to provide an acceptable and responsible level of control. That is the mission of the function. I submit, however, that this can only be achieved on a continuing and stable basis by giving priority attention to professionalization, an improvement in relationships and public acceptance.

To achieve this objective, animal damage control must operate from a position of strength within the existing state and federal structures. It must be supported as part of their mission -- not as an appendage, not as a separate entity. It must have credibility, respect, stature and influence as part of the organization -- and also throughout the resource, industry and agricultural communities.

This is one reason why I believe that the new arrangement with the Department of Agriculture and APHIS is so important. The initial support and direction has been provided. And, it is so refreshing and so long in coming. But now it will take individual performance and initiative to secure the gain. It is indeed a case of "pulling yourself up by your own bootstraps." The burden is on each worker, each supervisor and each administrator to demand and reach for the best professional performance and result. This is the surest path to providing acceptable and responsible levels of control.

All that I have discussed runs counter to the animal rights movement for that movement is diametrically opposed to animal use and management. It presents a most serious threat to all management programs. Its proponents are at work on many fronts: medical research, uses of farm animals, hunting, the wearing of fur and other examples, ad nauseum. And, they are working in a very effective and sophisticated manner with an emotionally appealing subject, with well known supporters, a sympathetic media, extensive use of the courts and effective lobbying efforts. They are a force to be reckoned with and a force that must be countered.

But, make no mistake -- there is a vast difference between animal rights and animal welfare. We would not be in the business of wildlife management if we were not interested in the well being of wildlife. Animal rights proponents, however, equate the rights of animals with those of humans. In our opposition to the animal rights movement, we do not want to oppose or even appear to oppose legitimate efforts to correct animal abuses. We don't want to throw the baby out with the bath.

I don't know what the answer is or what a workable broad strategy might be for dealing with the animal rights movement. I am convinced, however, that direct confrontation is not the answer. A successful strategy will need to be intelligent, sophisticated and broad guage. The International Association of Fish and Wildlife Agencies, along with others, is moving in that direction.

That movement will continue to frustrate animal damage control work at every turn. I believe that for now the best strategy and defense, insofar as animal damage control workers are concerned, is to conduct a professional, responsible program. At the same time, it will be important to monitor the movement and stay abreast so that all necessary responses will be professional and rational.

I am convinced that many circumstances come together to provide a real opportunity, a real challenge for the 90's. There is a good block of solid support for responsible control. The International Association of Fish and Wildlife Agencies and its member states and provinces are use oriented. They are wildlife managers. They will be supportive of responsible programs. The Association has, through all the years, been a cooperator and active supporter of responsible control. It will be testifying on an expanded APHIS budget this month. You may be sure this support and cooperation will continue.

We are at a point in resource management where individual performance and action are needed. I am confident it will be forthcoming.

Thank you and good luck!

The Current Program and Future of ADC in the USDA[1]

Bobby R. Acord[2]

The ADC program was transferred to the U.S. Department of Agriculture, Animal and Plant Health Inspection Service in December 1985. The ADC mission continues to be the protection of American agriculture and other resources from wildlife damage. Changes have been implemented to enhance the program, and efforts are continuing toward additional improvements.

As most of you are aware, the Animal Damage Control (ADC) Program was transferred from the U.S. Department of Interior-Fish and Wildlife Service (USDI-FWS) to the U.S. Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS) about 3 years ago. The APHIS-ADC mission continues to be the protection of American agriculture and other resources from wildlife damage. There have been a number of changes in the structure and organization of our program since the transfer to USDA. Today I'd like to discuss some of the changes we've seen since 1985 and outline the direction that ADC is taking to deal with some of the major issues confronting our program at the present time.

One of the measures undertaken by ADC to assure the long-term effectiveness of the program has been the formation of a Strategic Long Range Plan. ADC's Top Management Team (TMT) identified and assessed apparent program strengths and weaknesses, external influences and relationships, and conditions that would ensure continued program vitality. Based on these factors, the TMT identified a set of strategic goals for ADC and developed a plan for their achievement over a 5-year period. We are currently pursuing strategies to achieve many of these goals, and we're optimistic about where the full implementation of this plan is going to take the ADC program.

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop, Fort Collins, Colorado, April 17-20, 1989.

[2]Bobby R. Acord is Associate Deputy Administrator, Animal Damage Control, APHIS, USDA, Washington, D.C.

Another positive step taken to improve our program since the transfer to USDA has been the establishment of a National Animal Damage Control Advisory Committee (NADCAC). NADCAC is composed of 20 members chosen from nominees by the agriculture industry, conservation and environmental groups, land use groups, and wildlife agencies. The purpose of this committee is to make recommendations to the Secretary of Agriculture on policies and program issues regarding wildlife damage control. Issues and problems addressed include wildlife interfering in agricultural production, jeopardizing human health and safety, and creating nuisance problems in urban areas. NADCAC has been very supportive of ADC, and their recommendations have been extremely helpful in guiding the program.

One of the most important issues ADC is currently involved with is the completion of a programmatic environmental impact statement (EIS). APHIS is legally required by the National Environmental Policy Act (NEPA) to conduct an EIS on the ADC program. The EIS under which we now function was completed in 1979 while the program was under the FWS, and covered only the western predator control program. This EIS was formally adopted by APHIS as an interim measure, but was to be replaced as soon as possible. Efforts are well underway toward completion of the new EIS, which will cover the entire program. We have been working closely with the EIS contractor, Dames and Moore, and the draft EIS is due to be released later this year.

One issue that's presented somewhat of a challenge for ADC since the transfer to USDA has been the resolution of migratory bird damage problems. These include waterfowl and blackbird depredations on grain crops, depredations by fish-eating birds at aquaculture facilities, and bird/aircraft strike hazards at airports. While ADC is

responsible for addressing these problems, we have encountered some obstacles because we have had no management or regulatory authority. This authority lies with the FWS, and we are currently working closely with FWS people to overcome some of the regulatory obstacles to dealing with migratory bird problems. We're optimistic about these negotiations and are looking forward to being able to solve these problems more effectively in the near future.

Another area of particular concern to our program has been predator control on public lands. This issue is coming under increasing public scrutiny. There are a lot of people out there who are very much against any kind of predator control program being conducted on public lands. On the other hand, the livestock industry at times suffers tremendous losses to predators on these lands, and this industry relys on ADC to help protect their resources. The Forest Service (FS) and Bureau of Land Management (BLM) are becoming very cautious and often more restrictive in allowing predator control on public lands. Increasingly these agencies want to dictate types of control tools used as well as the placement and timing of their use. These decisions are often being made by managers with limited ADC expertise in response to pressure from the public and environmental groups. This has made it more difficult at times for us to carry out our mission. We continue to work closely with FS and BLM policy officials, and are optimistic that we'll be able to address concerns on both sides of the issue and still do our part to protect the agricultural resource.

With the transfer to USDA there has been a change in outlook on the kind of work we ought to be doing, with increased emphasis placed on the protection of agriculture and human health and safety. This change has carried over to ADC's research unit, the Denver Wildlife Research Center (DWRC). The focus of research efforts has now shifted more toward solving specific ADC problems. A strong research effort is vital to the continued success of our program. All of the tools that we have now are our "life blood," and we need to maintain the use of these tools to accomplish our goals, but at the same time we have to start looking at a new generation of control tools--replacements for the tools we're now using in case we eventually lose these. The tools that are going to provide us with effective animal control in the ecological, cultural, and political climate facing us 10-20 years from now will be based on today's investments in long term research. USDA has requested funds to upgrade DWRC facilities and equipment to bring them into compliance with EPA's Good Laboratory Practices and the Animal Welfare Act. These improvements are needed, and they will allow research to better meet the future demands of the ADC program.

In addition to other research, DWRC is responsible for the registration of all the pesticides used in ADC. Pesticide registration is a complicated and expensive process. Costs for registration of a new chemical can range from $5,000 up to $20,000,000 or more, depending on the intended use for the product. Maintaining existing registrations is also expensive. For example, to maintain the registration of strychnine products, additional data requirements have to be completed by ADC and submitted to EPA within the next 2 years. Estimated costs for these data call-ins range from $500,000 to $3 million. Our program has been underinvesting in research to develop data necessary for the maintenance of pesticide registrations, and we're currently trying to catch up. ADC research is dedicated to developing new pesticides and maintaining the registration on those products that are vital to our program. The improvements to DWRC mentioned earlier will help with this endeavor. Increasing costs, increasingly restrictive environmental regulations, and increased opposition to chemical control methods present a challenge to our efforts. ADC will continue to develop and maintain effective control tools that best serve the requirements of the ADC community.

Another issue relative to pesticide registration that is confronting ADC right now is EPA's new Endangered Species Pesticide Labeling Program. The intent of this program is to ensure that the use of pesticides does not threaten the survival of any threatened or endangered species. This is a very complex program being implemented under the authority of the Endangered Species Act, which is administered by FWS, and the Federal Insecticide Fungicide and Rodenticide Act (FIFRA) which is administered by EPA. The program was first announced by EPA in May 1987, and originally was to be fully implemented by February 1988, but is still on hold. It's been quite controversial because if implemented as originally designed, the net effect of the new labeling requirements would have meant severely restricting or eliminating the use of many pesticides registered for use by ADC. Currently EPA, USDA, and the USDI are all working toward revising and improving these labeling requirements to assure the protection of endangered species while still permitting the essential use of pesticides. This program will undoubtedly affect the way ADC operates in some areas, but we can't fully estimate the magnitude of this effect until the scope of the labeling program is completely known.

We all recognize the need to protect endangered species, and ADC is actively involved in efforts toward this goal. In cooperation with other agencies, control programs have recently been initiated to protect endangered species such as the desert tortoise, California least tern, and several species of Hawaiian birds. We are also involved in efforts to control damage caused by one endangered species, the eastern timber wolf in Minnesota. We have responded to this problem by removing those animals that are responsible for the livestock loss. This control program complies fully with the endangered species regulations, and is accomplished through the cooperation of ADC, FWS, and the Minnesota Department of National Resources. ADC involvement with the control of endangered species could increase in the future, either as a result of the natural expansion of endangered species populations, or the reintroduction of endangered species into their former ranges.

Another project we currently have underway is modernization of our Management Information System (MIS). This is a computer based system that records, processes, stores, and reports information that pertains to the operational activities of the program. The MIS was developed in the late 1970's to assist with the informational needs of western State programs, but it only became operational in Arizona, California, New Mexico, Oklahoma, Texas, and Utah. The MIS records and maintains data on resources, damage, control methods used, and animals taken. This system generates a variety of reports derived from these data, including some for internal use and others for submission to State or cooperator entities. Use of the MIS has enhanced the credibility of the ADC program with other Federal, State, and local agencies. However, due to equipment obsolescence, and the need for a uniform system to serve the entire ADC program, the current system has reached its effective limits. A long-range project has been initiated to redesign the system using updated, state of the art hardware and software, and we believe it will provide the database for a decision support system that will improve the overall efficiency of the ADC program. The new system is expected to be operational in all States in 2 years.

Animal damage is being recognized throughout the U.S. as a serious problem, and interest in the ADC program is high. Congress has responded by increasing funding for ADC. We've gone from a budget of 19.4 million at the time of the transfer to a proposed budget of 29.8 million for FY 1990. We're expanding to address a wider range of species and the entire spectrum of wildlife damage problems. We're developing additional cooperatively funded operational programs in the East, and there is widespread support for developing more of these programs. Right now we have cooperative beaver control programs to protect timber in Kentucky, Tennessee, and Mississippi, trout streams in Wisconsin, and endangered freshwater mussel habitat in Louisiana. We also have cooperative damage control programs for Canada geese in Wisconsin and Tennessee, coyote control in New York, gull control at a U.S. Army facility in Michigan, and a nuisance grackle control program in Georgia. Part of the increase proposed for FY 1990 will be used to begin cooperative programs in those States that already have funds set aside for this purpose.

We have strong support within USDA for the ADC program. In the early days of the transfer from FWS there may have been some misdirection of our program, but now we have genuine ADC people leading the program, and we feel we're heading in the right direction. C. Joe Packham, our Deputy Administrator comes from a strong ADC background, and has made great progress in leading our program forward. Employee morale is high, and our people are enthusiastic about their work.

We have embarked on an aggressive staff recruitment and development campaign so we can maintain a qualified and competent workforce. Two years ago, we hired the first ever Supervisory Training Program class for the ADC program. Twenty wildlife biologists were selected from across the Nation and underwent intensive training. These people have become a vital part of our workforce. This class was hired in anticipation of a real drain on our supervisory workforce within the next 3-5 years, due primarily to retirements. Another recruitment avenue we've started using is that of cooperative education students. We are seeing more incorporation of ADC issues and functions in the curriculum at some major universities, and we're working with some of these institutions to develop cooperative education programs. There is getting to be a greater appreciation for ADC as a science in the academic community, but we need to continue working on this.

One of the things that we as leaders in the field of ADC have got to recognize is that there are different perspectives on ADC work, and we've got to attempt to deal with them. As our population grows and becomes more urbanized, the people involved in producing our nations food and fiber are becoming a smaller and smaller minority. This results in an increasingly larger percentage of our population that are not directly affected by the problems that wildlife may create for agriculture or the threats it may pose to public health and safety. The environmental

movement has resulted in increasingly restrictive regulations and opposition to ADC activities. All of these factors highlight the need for an education program, that when presented to the public in an unbiased fashion, will show how important ADC work really is. It's important not only for protecting agricultural products and economic interests of the producers, but for protecting the economic interests of the American consumer as well. We have long-range plans for developing and implementing a public information/education program that hopefully will lead to a greater understanding and appreciation of the need for control of wildlife damage.

We need to emphasize to people that we are not an animal control agency--we are a <u>damage</u> control agency. We emphasize the principles of Integrated Pest Management, and our sole interest is in resolving conflicts as efficiently and in as environmentally acceptable a manner as possible. At the same time there needs to be recognition that American agriculture is not going to provide the habitat and feed the Nation's wildlife free of charge. One of the most detrimental things that could happen to the wildlife resource is to be forced into indemnity for damage caused by its presence. An effective damage control program is a much cheaper alternative. It's up to us to see that it happens!

With the current leadership and support we have from USDA, NADCAC, the agricultural community, our cooperators, and our workforce, we're looking forward to providing the American public with an increasingly valuable service.

Planning for Animal Damage Control Programs within the Animal and Plant Health Inspection Service[1]

Philip S. Gipson and Gary P. Combs[2]

Abstract.--The Animal Damage Control Unit (ADC) and the 10 other units of the Animal and Plant Health Inspection Service (APHIS) have undergone major reorganization. Emphasis is placed on planning and risk analysis. Four levels of planning have been identified: (1) strategic planning for the Agency, (2) strategic planning for each of the 11 units, (3) program design and risk analysis, and (4) operational planning.

INTRODUCTION

APHIS and the ADC Unit have undergone changes that impact American agriculture and the ways wild animals are managed to reduce conflicts with man. In 1987, an APHIS management review group was formed consisting of 11 members from programs and support areas to review the Agency with emphasis on how the Agency could better service American agriculture and the Nation (Helms, 1988). The leadership of APHIS undertook a reorganization of the Agency based on recommendations from the review group. Personnel were assigned to new units and APHIS started to function under the new organization in October 1988. The publication, APHIS, Changing for the Future (Anonymous, 1988), describes the new organization of APHIS.

In December 1985, ADC was transferred from the Fish and Wildlife Service (FWS), Department of the Interior, to APHIS, Department of Agriculture, by Public Law 99-190. ADC became the third major operational unit in APHIS along with Veterinary Services (VS) and Plant Protection and Quarantine (PPQ). The fourth unit of APHIS was Management and Budget (MB). At the time of the transfer, APHIS intended to conduct ADC operations that were biologically sound, environmentally acceptable, and economically feasible.

ADC was placed under the direction of a Deputy Administrator, and the number of ADC regions was reduced from seven that existed under the FWS, to two; one for western States with headquarters at Denver, Colorado, and one for eastern States with headquarters at Brentwood, Tennessee. The Denver Wildlife Research Center (DWRC) and its field stations remained part of ADC and continued to be managed from Denver. At this time, APHIS initiated planning to prepare an Environmental Impact Statement for ADC, to provide guidance, and to assure that animal damage control activities were in compliance with the National Environmental Policy Act (NEPA). Historical reviews of ADC prior to the transfer to APHIS were authored by Wade (1980, 1986).

The purpose of this paper is to explain how planning for new animal damage control programs and revisions of current programs will be conducted in the reorganized APHIS.

THE NEW APHIS

The APHIS reorganization is primarily a headquarters reorganization designed to improve the way decisions are made and to provide better support to operational programs. Emphasis is placed on planning and risk analysis to address concerns about protection of the environment, use of pesticides and other chemicals, animal welfare, and rapidly changing agricultural industries. Multidisciplinary teams of specialists from within APHIS, the academic community, and industry are used to address these complex issues.

Planning and risk analysis are taking place at all levels within APHIS, and they are the focus of this paper. Figure (1) shows the new organization of APHIS. The Agency has gone from 4 major units (PPQ, VS, ADC, and MB) with support from the

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop, Fort Collins, Colorado, April 17-20, 1989.

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Animal and Plant Health Inspection Service

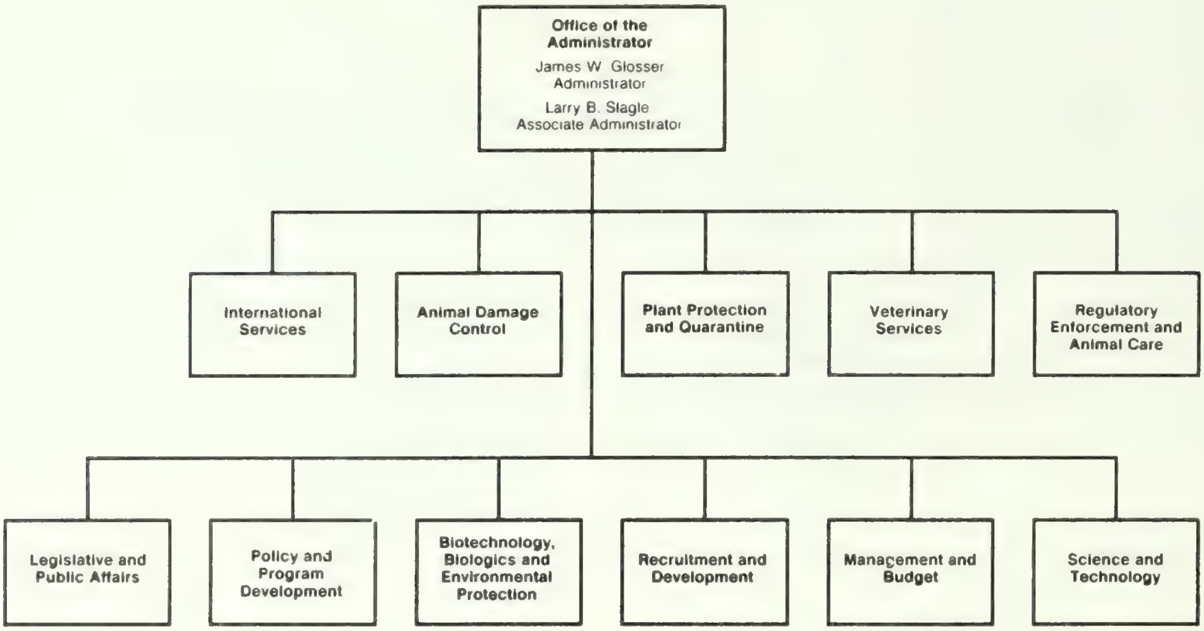

Figure 1. Organizational chart for the Animal and Plant Health Inspection Service (APHIS). Each of the 11 units along the parallel lines has a Deputy Administrator or Director who reports to the Administrator of APHIS.

Legislative and Public Affairs staff and the Biotechnology and Environmental Coordination staff to 11 major units, each with a Deputy Administrator or Director that reports directly to the Administrator of APHIS.

Since the reorganization, ADC includes the office of the Deputy Administrator, Eastern and Western Operational Regions, an Operational Support staff in Hyattsville, Maryland, and a Resource Management staff in Hyattsville.

CHANGES IMPACTING ADC

Two major changes within APHIS have marked impacts upon ADC. First, DWRC and other APHIS laboratories have been assigned to the Science and Technology Unit (ST), and the directors of the laboratories now report to the Director of Science and Technology rather than to the Deputy Administrators of ADC, PPQ and VS, respectively.

DWRC will continue to address needs of ADC, but emphasis must be placed on maintaining communications between researchers at DWRC and ADC operational professionals. DWRC is unique among the APHIS laboratories by having authority to conduct research as well as test and develop tools to serve the ADC Operational Unit. Other APHIS laboratories conduct tests and develop technology to serve the needs of VS and PPQ, but the Agricultural Research Service conducts research for animal and plant pest and disease programs. A formal planning and evaluation process is needed to assure that effective communications occur between the APHIS laboratories and operational programs, and that researchers at DWRC and the Agricultural Research Service are responsive to current and future APHIS operational needs.

The second major change impacting ADC relates to planning and risk analysis. A new unit, Policy and Program Development (PPD), has been formed within APHIS to conduct and facilitate planning, program evaluations, program design, risk assessment, policy analysis, and regulation development. One section of PPD that directly serves ADC is Animal Health and Depredation Management Systems (AHDMS). This section also coordinates program design and risk assessment for VS and other units of APHIS concerned with animal health, animal welfare, environmental issues, and management of wild animals.

PLANNING WITHIN APHIS

Planning within APHIS occurs at four levels (Figure 2). The first level of planning, APHIS strategic planning, is being developed by the APHIS Management Team (AMT) composed of Deputy Administrators and Directors of the 11 units of APHIS. APHIS strategic planning is guided by the Planning and Evaluation section (PE) of PPD.

The second planning level is strategic planning for the 11 units. The Deputy Administrator of ADC and the Deputy Administrator or Director of each of the other 10 units of APHIS are developing strategic plans for their respective units.

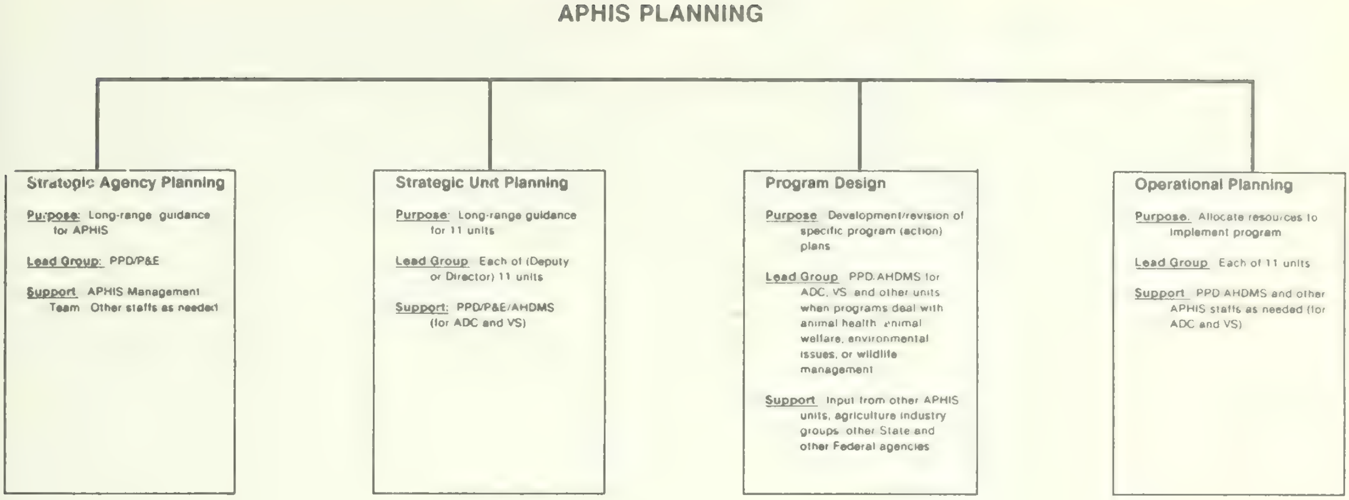

Figure 2. Levels of planning within APHIS.

The third level of planning involves development of long-range goals. Program design is an important part of this process. Design or modification of ADC programs may be needed when new damage threats develop, agricultural production changes, and when technology for controlling damaging animals changes. An example of a new threat to livestock is the recent establishment of wolves in Montana and other States. The rapid expansion of aquaculture, especially in southern States, is an example of a change in agricultural production that calls for ADC planning because of increases in damage from fish-eating birds. An example of a change in animal control technology that should be evaluated for use in ADC programs is refinement of the padded jaw trap.

AHDMS will play a lead role working with ADC and VS to design new programs and to revise ongoing programs. The analysis of risks associated with new or current programs will be an integral part of program design. The process used to design a new ADC program is presented in Figure 3.

The fourth level of planning, operational planning, takes place within each unit to set annual program objectives and allocate and manage resources. For example, once a new ADC program is designed, the ADC Unit will develop short-term operational plans to implement the program.

APHIS is trying to avoid pitfalls that other agencies and industries have sometimes encountered

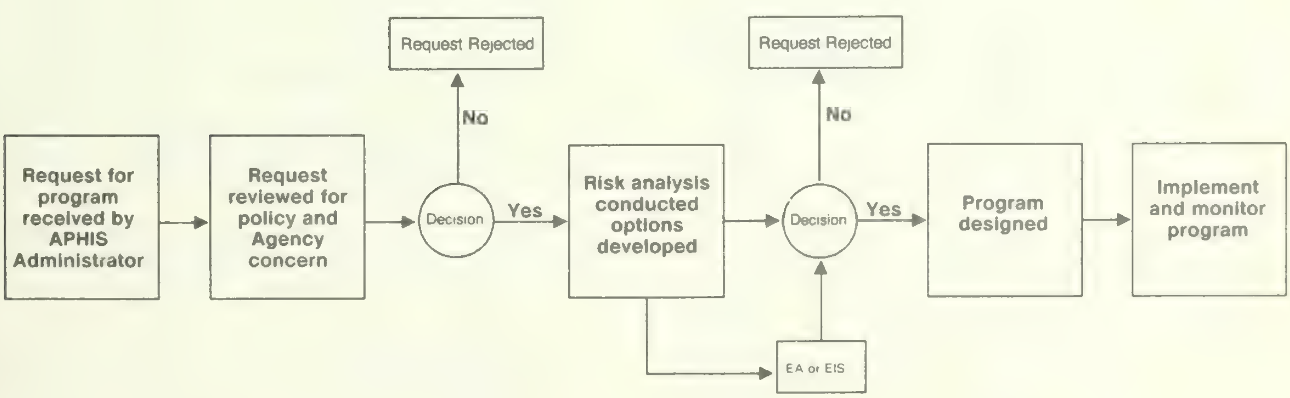

Figure 3. Key steps in review, design, and implementation of ADC programs.

when they hired a consulting firm to do planning or assigned planning to a separate section of the organization. Often this approach resulted in plans not being fully implemented (Below, et al., 1988). APHIS planning involves managers and specialists from all sections of APHIS, as well as specialists from outside the Agency, and interests groups. This involvement should gain acceptance of the processes used in planning and it should gain credibility for the plans produced.

ISSUE MANAGEMENT

An issue management process has been established for APHIS to enable timely identification, assessment, and resolution of emerging threats and opportunities for agricultural protection. When a critical issue is identified, an interdisciplinary analysis team is organized. These teams are composed of specialists from within APHIS and when needed, specialists from the scientific community and interest groups.

Critical issue teams may recommend a variety of actions including a formal program design review as outlined in Figure 3. Such a review could, in turn, lead to a new APHIS program. Other possibilities would be to outline specific steps APHIS should take to solve a crisis, or the committee could conclude that the issue was outside the area of responsibility for APHIS and recommend that APHIS take no action.

An example of a critical issue involving ADC and other units of APHIS is pesticide use. This became a critical issue for ADC when the Environmental Protection Agency announced plans to cancel registrations for products containing compound 1080 and strychnine. A team was established to review pesticide uses in ADC and to recommend actions. However, it was quickly recognized that pesticides, as defined by the Federal Insecticide, Fungicide, and Rodenticide Act (Public Law 100-532, 1988), are also important in animal health and plant protection programs, and a larger committee was established to review the status of pesticide use by all APHIS programs. This committee is composed of specialists from PPD, ST, and a pesticide specialist from private industry. The first action taken by this committee was to prepare an inventory of pesticides used showing the status of each pesticide.

RISK ANALYSIS

Risk analysis is part of the process used to manage critical issues, design new programs, and revise current programs. Risk analysis involves two elements: risk assessment and risk management (Stallones, 1983). Risk assessment is a scientific evaluation of the probability associated with a threat occurring and the magnitude of that threat. Risk management is the design of program strategies to deal with a threat and implementation of the resulting plan.

APHIS units deal with many types of risks. For example, there is a threat of brown tree snakes, Boiga irregularis, becoming established on Hawaiian Islands and other islands, especially in the Pacific Ocean (Fritts, 1988). Experience with brown tree snakes on Guam suggests that the establishment of brown tree snakes on other islands would have negative impacts to poultry and small mammals, wild birds, and public electrical service.

A risk analysis of brown tree snakes establishing on Pacific islands would first assess the threat (risk) of brown tree snakes becoming established on key islands. The likelihood of brown tree snakes being introduced and populations established would be assessed as well as the magnitude of the threat they would represent to animals and electrical utilities. The second step would be risk management for brown tree snakes, which might involve inspection and treatment of arriving cargos and possibly new regulations controlling importation of snakes.

DISCUSSION

The Animal Damage Control Unit (ADC) and the 10 other units of APHIS have undergone changes associated with reorganization of the Agency. The reorganization was designed to improve support to field program delivery through better planning, analysis, and use of resources. It also creates a stronger APHIS identity through interdependence and cooperation among the 11 units of APHIS.

Emphasis is thus placed on planning and risk analysis in the reorganized APHIS. Four levels of planning have been identified (Figure 2): (1) strategic planning for the Agency, (2) strategic planning for each of the 11 units, (3) program design and risk analysis, and (4) operational planning. Animal Health and Depredation Management Systems (AHDMS), a section of PPD, will work closely with ADC to facilitate planning for new ADC programs and revisions to current programs. AHDMS will also facilitate working linkages between ADC and other units of APHIS.

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Status of Strychnine, Compound 1080, and Registered Alternatives[1]

Steve D. Palmateer[2]

Abstract.--This paper reveals the current regulatory status of 1080 and strychnine relevent to data call-in actions, administrative hearings, and litigation outside of FIFRA. All strychnine prairie dog claims are cancelled as well as all label claims requiring a tolerance. The 1080 technical is cancelled and all rodenticide uses have been issued a notice of intent to deny.

The Rebuttable Presumption Against Registration (RPAR) notice (now called Special Review), for 1080 and strychnine was published in the FEDERAL REGISTER of December 1, 1976. The presumption was against all outdoor above-ground uses of strychnine and all uses of Compound 1080. Three other actions by the Federal government should be noted. In March 1972, Executive Order 11643 was issued. This order prohibited the use of all toxicants, including strychnine, for control of predators on Federal lands or in Federal programs. In the same year, the Environmental Protection Agency (the Agency) cancelled the registrations of thallium sulfate, cyanide, strychnine, and Compound 1080 for predator control. Additionally, in February 1978, the Agency restricted products of several active ingredients, including strychnine formulations with concentrations greater than 0.50 percent, for use by certified applicators. The criteria influencing the restriction for strychnine were significant acute oral toxicity, apparent hazards to nontarget species, and the results of use and accident history.

The RPAR criteria that were determined to have been met exceeded for the outdoor above-ground uses of strychnine and all uses of Compound 1080 were: 1) acute toxicity to mammals and birds, and 2) significant reduction in populations of nontarget organisms and fatalities to members of endangered species.

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1 Presented at the Ninth Great Plains Wildlife Damage Control Workshop in Fort Collins, Colorado on April 18-19, 1989.

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Position Document 2/3 (PD 2/3), which detailed the Agency decision on strychnine, was published for comments in November 1980 for strychnine and in June 1983 for Compound 1080. In these documents, EPA proposed cancellation of many of the uses for both of these vertebrate pesticides or at least modification in terms of use. As you might expect, the Agency received numerous comments on the PD 2/3 documents. The most common criticism was that the Agency had very little definitive data to support its conclusions. The Agency felt that its worldwide literature search had yielded enough data to provide a basis for concern about potential risks to nontarget organisms. Also, as clearly required under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the responsibility for establishing the safety and efficacy of both of these vertebrate pesticides rests with the registrant and not with the Agency. A complete data base for both strychnine and 1080 had not been generated, in large part because of the uncertain registration status of the pesticides.

Therefore, EPA has issued three Data Call-In (DCI) Notices for strychnine and two for Compound 1080. EPA required that all products be supported by data necessary for registration under section 3. These actions were taken under the authority of FIFRA section 3(c)(2)(B) based on the determination that the additional data were needed to support the continued registration of both strychnine and Compound 1080 products.

The Agency required product chemistry, environmental fate chemistry, toxicology, and wildlife and aquatic organism testing. The Agency also requested the development of tolerances for these products if there is foliar contact of the pesticide with a food or feed crop, uptake of the pesticide in a food or feed crop from the soil,

or direct contact of the pesticide with a livestock animal (e.g., dermal contact or ingestion of treated bait), in which case the application is a food use, and food use requirements will apply. Under these circumstances, a petition for tolerance or a petition for exemption from the requirement of a tolerance is required to support registration. All registrants revised their labels to reflect nonfood uses to avoid the tolerance requirement.

EPA reviewed the data requirements very carefully before issuing the DCI documents. EPA feels that the requirements were kept to an absolute minimum to avoid unnecessary data-gathering costs and yet at the same time to provide adequate data in order to make a scientific regulatory judgment about the risks and benefits of Compound 1080 and strychnine. Several registrants requested waivers and/or postponement of data requirements and presented persuasive rationales why the waivers should be granted enabling the Agency to grant these requests.

In October 1985 and again in October 1987, EPA sent a group of its scientists and other staff to public meetings in Denver, Colorado, to explain why the data were needed, how the data should be generated, and describe the standard format for data submitted under FIFRA. The Agency also sent its vertebrate pest biologists to a meeting of the strychnine registrants held in conjunction with the Thirteenth Vertebrate Pest Conference in Monterey, California in March 1988. The most important development at this meeting was the formation of the strychnine data-gathering consortium headed by the U.S. Department of Agriculture Animal and Plant Health Inspection Service, Animal Damage Control (USDA/APHIS/ADC). From the beginning of the strychnine consortium, the Agency has attempted to be helpful to the group (e.g., supplied names and addresses of all strychnine registrants, clarified many of the data requirements, reviewed hundreds of protocols, and made hundreds of determinations of data applicability from one registrant to another). USDA/APHIS/ADC personnel were a particularly fortunate choice by the consortium to be the lead as they have quickly learned the EPA regulatory process and have kept the data-gathering costs to a minimum. In particular, we would like to single out two of the USDA's Denver personnel, Edward Schafer and Kathleen Fagerstone, who have been proficient and professional in their transactions with EPA.

STRYCHNINE

In spite of a efforts by EPA, USDA/APHIS/ADC and others to facilitate the strychnine data-gathering process, it became apparent in October 1988 that the strychnine data requirements were not going to be satisfied in a timely manner. Therefore, on October 6, 1988, the Agency sent Notices of Intent to Suspend to all strychnine registrants for failing to submit product chemistry and/or failing to show significant progress towards satisfying the wildlife safety-efficacy data requirements. Notices of Intent to Suspend were sent to 99 companies with a total of 383 products suspended with the California Department of Food and Agriculture (CDFA) and many California counties holding about 250 of the strychnine registrations.

Fifty-six of the registrants (including CDFA acting as agent for 37 California counties) requested a hearing to avoid suspension. A prehearing was held in San Francisco, California, on November 30, 1988 at which the Agency and the affected registrants agreed to attempt an out-of-court settlement. On February 14, 1989, the final settlement document was mailed to all affected strychnine registrants and by March 2, 1989 all parties had signed the agreement. On March 10, 1980, the ALJ approved the settlement.

Several significant label claims have been eliminated as a result of the DCI Notices and/or litigation. Under terms of the settlement, strychnine products may not contain label directions for any food or feed use. Specificially, general broadcast applications of strychnine products are not allowed around food or feed crops. You should be aware that the Agency considers pasture and rangeland a feed use as a pesticide may be ingested by livestock and transported into milk or meat. The significant label target species claims eliminated are house mice, prairie dogs, and porcupines. However, there are still label claims for pocket gophers, microtus, kangaroo rats, marmots, hares, cotton rats, moles, pigeons and several bird species, although some of these species may be required to be dropped in the near future depending on whether registrants decide to produce supporting data.

In a related strychnine action on April 11, 1988, the United States District Court for Minnesota issued an injunction against the above-ground uses of strychnine. The court ordered that EPA temporarily cancel all above-ground uses. Therefore, on May 4, 1988 the Agency sent a letter to all strychnine registrants apprising them of the Minnesota court's April 11, 1988 decision and enclosed with this same letter a copy of the court order. On September 30, 1988, the Agency mailed to all registrants a copy of a notice of temporary cancellation signed by the EPA Administrator. This notice was issued by EPA to avoid a contempt citation. The notice did not rely on the authority of FIFRA but on the enforcement authority of the District Court in Minnesota under its own order. Under this proposal, registrants, distributors, and users of strychnine would be subject to contempt of court proceedings if they did not comply with the order.

1080

In October 1988, the Agency also determined that it was not going to receive the data requested for both the 1080 technical products and the end-use products. Therefore, on October 4, 1988 the Agency mailed a Notice of Intent to Cancel the one Compound 1080 technical product.

This product had a conditional registration which required submission of satisfactory data to satisfy the requirements of the November 22, 1985 DCI Notice.

Several 1080 user groups felt they were adversely affected by the cancellation notice and requested a hearing to contest the cancellation. The Agency requested an accelerated decision based on failure of the Compound 1080 technical manufacturer to submit the data in a timely manner and the failure of the same registrant to comply with the Agency's December 17, 1987 offer to extend the data requirement due dates. The petitioners raised the issue of economic loss to farmers and ranchers and that the cancellation would affect the public health. The Administrative Law Judge (ALJ) ruled in favor of the Agency on the fact that none of the petitioners had challenged the basis of the notice of cancellation. On February 21, 1989, the ALJ issued a preliminary decision and cancelled the product, pursuant to regulation.

In a similar action, the Agency mailed a October 4, 1984 "Intent to Deny Applications for Federal Registration of 1080" to 19 California counties and to the Colorado Department of Agriculture in addition to a Notice of Intent to Suspend to Klamath County, Oregon. At this writing, the Agency has not mailed denial notices to either the California counties or to the Colorado Department of Agriculture.

USDA/APHIS/ADC has submitted an application for registration of a Compound 1080 technical product to be used only in the 1080 livestock protection collar. Since the data base for the 1080 collar use is nearly complete, the Agency is requiring only a small amount of product chemistry data to complete all the data requirements. To date, Montana Department of Livestock, Wyoming Department of Agriculture, South Dakota Department of Agriculture, New Mexico Department of Agriculture, USDA/APHIS/ADC, and Ranchers Supply of Alpine, Texas have registered the 30 mL livestock protection collar.

The Agency has registered several new use patterns for old chemicals. These new use patterns include zinc phosphide and chlorophacinone baits for pocket gopher control, and has greatly expanded the sites and pest claims for 1339 as a gull toxicant.

A new DCI Notice has been issued for warfarin as a followup to the Warfarin Registration Standard issued in September 1981. The warfarin DCI requires very little new data as the registrants will be requested to submit or cite previously submitted data. All registrants will be requested to make label changes. Also, at this point, the data base for zinc phosphide products is not complete and EPA may have to take administrative action to expedite the submission of data on this compound.

The Landowner's View and Recommendations on Wildlife Damage[1]

Michael G. Leroux[2]

Conflict between landowners and state and federal agencies is prevalent in todays society. This report attempts to provide understanding of the landowners views on wildlife damage and offer some solutions to be considered.

INTRODUCTION

The individual landowner's point of view is based upon economic, historic and idealogical values that have led that individual to choose the lifestyle of an agricultural producer. These values vary, depending upon the individual's background, financial situation and goals for the future. These values need not conflict with the overall social patterns of regulation and wildlife management if sufficient flexibility is retained within the regulation and management to permit the landowner to continue to implement his values. When regulation does not acknowledge or find the full effects of a given regulation upon the landowner, or when regulation forces are an unexplained or unsubstanciated burden upon the landowner, conflict will arise between the landowner and the regulating agency and often the species sought to be protected by the regulator.

ECONOMIC CONCERNS

Pest and predator loss is a direct economic burden on the agricultural producer. Losses due to increased numbers of livestock predators, grain eating birds, and loss of productivity due to prairie dogs and ground squirrels can have devastating effects upon an already minimal profit margin for the producer. Additional costs of cleaning up and repairing property damage after the presence of such pests is also an added burden on a fragile economy.

[1] Paper presented at the Ninth Great Plains Wildlife Control Workshop. (Marriot Hotel, Fort Collins, Colorado April 17-20, !989)

[2] Michael Guy Leroux is a fourth generation Colorado Landowner and member of Colorado Farm Bureau, Denver, Colorado.

HISTORIC CONCERNS

Historically, the landowner was able to eliminate pests and predators through whatever means he chose. Poisoning, trapping, and unlimited removal by shooting were all economical means to offset damage. With concerns about losses or massive reductions of numbers of several species, due to heavy hunting pressure from all sectors of society or due to externalities of a given pest control problem such as improper use of poisons, society, through state and federal legislation, placed limits upon the means by which a landowner could protect his economic welfare. While regulation attempted to protect the endangered or preferred species, it did not and has not adequately taken responsibility for increased hardship upon the landowner. It has taken an historical right from the landowner without offsetting this loss with adequate remedy for additional losses the landowner must bear. This is in direct conflict with the historic, economic and idealogical views of most landowners.

LANDOWNER IDEOLOGY

The ideology of most landowners is no different from that of any property owner. Generally the owner has reviewed the costs and benefits of owning a given piece of property and if benefits exceeded costs the individual sought title to the property. In a similar way, most individuals weigh the costs and advantages of owning a home or an automobile before purchasing one. In both cases once the property is purchased, the new owner feels that they have the right to protect and control the environment within the acquired property. In the landowners view he has purchased legal rights to the property and to all produce grown on that property.

Often the property may have pests that reside on the property. For instance, a homeowner may have a family of mice that live in the wood pile. As long as the mouse numbers stay within an acceptable range and do not create more than an acceptable amount of damage

to the property owner, the mice and the landowner will live in harmony. Once these thresholds have been overridden, such as the mice family expanding into the linen drawer, conflict will arise between the property owner and the wild life (the mouse) destroying the equibrium of the past mutually accepted situation. The property owner generally reduces the number of mice to a point below the originally accepted threshold and thus restores equilibrium. Historically this same procedure was used by private landowners to retain equilibrium on their property in regard to pests such as predators, birds, rodents, big game and weeds. State and federal legislation have limited the landowners rights through agencies such as the Colorado Division of Wildlife and the Environmental Protection Agency.

Imagine the impact on your life if you could no longer defend yourself from competition for property rights in your home from rats, mice, snakes and pigeons, and the regulators were unwilling to provide restitution for the damage that their regulation caused you. You are in a situation similar to what present large landowners face. Not only would you be unhappy with the regulating agency you would most likely have developed a hostile attitude toward the mouse that at one time you were willing to tolerate within certain levels. We have developed a three sided conflict by improperly implementing regulation. This is the same type of conflict as we now have between wildlife, the landowner and state and federal agencies.

BIG GAME ANIMALS

Big game species are protected under state laws limiting the control of animals that cause economic hardship upon the rancher and farmer. Forage and growing crops losses, losses of harvested crops and damage to physical property such as fences and broken scattered wire and twine add additional economic, physical and emotional stress to the situation. Psycological stress due to losses of projected yields, loss of projected future feed supplies and reduced palatability of forage and damaged feeds that lead to poor health of domestic livestock, placed added burdens upon the landowner. Most big game animal numbers have increased since landowners settled and increased the production of our agricultural areas and means of protecting landowners property have been decreased. Minimal restitution is provided to the landowner for direct losses of stored feeds consumed by big game, yet little or no compensation for other losses has been adequately addressed by the state. Landowners face additional expenses through having to repair damage done by big game hunters to fences and roads and through livestock losses due to hunters. Disease can be controlled in domestic herds through removal of infected animals and vacination only if nondomesticated animals do not continue to spread diseases such as brucellosis.

PREDATORS

Proven losses of livestock, to preditors, are partially covered by state law but with strong limitations as to what is proof of loss. As many predator kills are not immediately found, it is often difficult to prove predator involvement in the loss, much less have opportunity to catch the exact participating predator. The landowner must still accept the burden of the loss wether he is compensated or not. Removal of offending animals, when possible, and reduction of species in overcrowded areas could help to alleviate the problem. To control such predators as coyotes, proper use of poisons must be made available for landowners.

PRAIRIE DOGS AND OTHER PESTS

Control of pests such as the prairie dog, Richardson ground squirrel and starlings is another problem which has multiplied since regulation has limited the use of poisons and other means of control. The application time for poisoning these pests is critical and under current standards, available methods of control, availability of control substances and availability of legal application teams to permit timely control is not often possible. Concerns for endangered species such as the black footed ferret, though legitimate, have been over stressed in areas where no ferrets have historically been known to exist. While responsible control is definitely important for permitting continuity of all natural species, adequate pest control is equally important and adequate pest control methods need to be developed to satisfy both goals.

WATERFOWL AND OTHER BIRDS

The protection and purposeful introduction of migratory and other game birds has lead to losses of both harvested and unharvested crops to many landowners. Geese not only consume vast amounts of grains but they tend to ruin and destroy additional quantities through excrement and tramping. Similar to big game situations, the regulating agencies should accept responsibility for protection of and restitution for losses of landowners property.

FARM BUREAU POLICY RECOMMENDATIONS

Farm Bureau and landowners feel that if problems and concerns are presented, solutions for these problems need to also be recommended. The following are Farm Bureau policy recommendations as developed by their landowner membership.

State Responsibility

Farm Bureau supports maintenance of reasonable numbers of big game animals but feels that wildlife agencies should accept more responsibility for damages done by wildlife and

hunters. Wildlife agencies should provide compensation and protection for damages to fences and roads by hunters and provide funding for counties to provide search and rescue efforts for lost hunters. All loss of feed and/or standing crops and pasture and all property damage on deeded land should be considered eligible for loss claims and these claims must be paid in a timely manner by the Colorado Division of Wildlife. No ceiling should be placed upon the amount of damages the DOW may have to pay. Damages should be paid as they occur regardless of historic levels of wildlife. Posting private property and/or restricting, limiting hunting or selling hunting rights should not be cause for disallowing damages to a landowner.

If a mutually acceptable settlement on game damages can not be reached between the land owner and the Division of Wildlife, an arbitration panel should be set up to settle the dispute.

Ownership and resposibility for all predators and game animals should rest with the state and control be assigned to the Division of Wildlife. If it is necessary to kill wildlife to control damages the Division of Wildlife should accept this responsibility and not force the responsibility upon the land owner.

State and Landowner Relations

The Colorado Division of Wildlife should concentrate on using funds for providing adequate water and feed supplies for wildlife through improvement of currently controlled lands and for paying for game damages and damages caused by hunters, before seeking to purchase additional properties. Adjustments in animal numbers and feed and water changes should be done in cooperation with BLM and other federal agencies in such a way as to be compatible with adjoining ranchers. Private land should in no way be designated as wildlife habitat without consent of the land owners or be condemned for wildlife habitat. The wildlife agencies should seek mutually acceptable leases with landowners for use of their properties for wildlife habitat and hunting. The Division of Wildlife should not be in competition with agricultures private landowners.

No species of wildlife should be introduced into a new area, by The Division of Wildlife, without full knowledge of possible effects being provide to the affected landowners and receiving approval from the majority of these landowners. The wildlife agency should also be required to provide an environmental impact statement any time animals are relocated to any area.

Farm Bureau recommends that landowners be given preference for obtaining limited licenses for the season of their choice for big game that exists on their private land. This permit or license should be complementary and presented upon request.

Farm Bureau recommends that trespass laws be strictly enforced and support possible additions to make the laws more of a deterant than present laws. We recommend our schools put emphasis on teaching about trespassing, infringements of private rights and violations of individuals rights to privacy. The private property owner should not have any responsibility for any accident or injury to any party on his private property without permission. All persons who trespass should forfeit all rights for injury or death and the landowner should be absolved of any liability.

Preservation of Control Practices

For predators and pest all present control practices, including steel traps, snares, and denning should be continued. Under problem conditions, use of chemical toxicants should also be used or allowed under supervision of federal, state or county predator control departments. We recommend that registration and certification of M44 be sought and 1080 oat control be retained for control of ground squirrels and prairie dogs. The bounty system and better markets for hides and furs should be promoted. New methods for controlling and repealing predators should be researched. Aircraft control of coyotes should be considered a viable alternative.

The growing problem of eagles and domestic dogs should be recognized and the public educated so protective action can be taken. Domestic dogs should not be permitted to run unsupervised.

CONCLUSION

In conclusion, landowners view landownership as any other property right. When social concerns limit controls on wildlife, as the state claims authority over these animals, the state must also accept responsibility for the damages these animals may incur and in protecting landowners from this damage. When the state purchases private property in competition with other landowners, they must accept the responsibilities as any other neighbor. Through education and understanding, mutual agreements can be reached permitting each landholder to retain control of their own private property. If the DOW and the other agencies seek to find mutual goals with each individual landowner conflict will become much less a part of our lives. Unless property rights are definitely defined, transaction costs are kept at a minimum and wildlife is valued through direct current demand, of those individuals willing to pay for the costs of maintaining the wildlife, conflict will continue.

The Landowner's View of Wildlife Damage Control Techniques and Agency Programs[1]

L. Bard Field[2] and Ed Hansen[2]

Abstract.--This is an opinion or viewpoint paper. Ranchers, as landowners, depend on the land and environmental quality for the productivity and stability of their businesses. Therefore, they evaluate wildlife damage of their property relative to its effect on their businesses. Historically, ranchers have felt that wildlife damage techniques and agency programs have been ineffective, costly, bureaucratic, and incomplete. Compensation programs, which are a last resort to damage control, are also problem-ridden. Wildlife damage is typically a result of poor population control of wildlife. Landowners are in support of damage control programs which are effective, economical, complete and address the issues at hand and wish to be involved in the development of programs that meet these criteria.

INTRODUCTION

Agriculture, and cattle production in particular, has traditionally been a vital contributor to the stability, economic vitality, and culture of the western United States. Ranchers are the original environmentalists of this area, having protected, nurtured and lived off the land for many decades. The ecosystem in which ranchers live and operate has always included wildlife. Nonetheless, it is this very sector of the ecosystem, which ranchers and landowners respect, protect and support, that is the cause of a great deal of damage to personal property and a threat to landowner's businesses and livelihood. The solutions for prevention of wildlife damage of property are difficult, costly and not always popular with everyone involved. The sources and/or means for compensation to this damage are usually slow and do not fully compensate for the loss. In addition, the compensation process itself is problem-ridden. Nonetheless, wildlife damage is a very real and pressing problem, both for the landowner and wildlife agencies, and is one which must be dealt with logic, a willingness to compromise and fairness to all involved.

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop (Marriott Hotel, Fort Collins, Colorado, April 17-20, 1989).

[2]L. Bard Field is Director, Member Services/Communications, Colorado Cattlemen's Association, Denver, Colorado. Ed Hansen is owner/manager of Circle Ranches, Inc., Livermore, Colorado.

LANDOWNERS AND WILDLIFE - A BALANCE

Landowner's have allowed access and use of their private land and shared the resources of leased land with wildlife for many years. Ranchers, like most citizens, appreciate wildlife and wish to see them live, healthy, and flourishing. Yet ranchers are different from most other individuals in that they derive their livelihood and income from the land and its resources. This position is sometimes in conflict with wildlife needs. Ranching, because it is a goal-orientated, progressive business, typically results in improvement in the environment. This improved environment is also more desirable for wildlife, which can result in more conflict and competition between wildlife needs and landowner's objectives. While landowners may look kindly upon wildlife flourishing on their land, if their land and property are being destroyed by wildlife, they will protect their property against the destroying force.

Damage by wildlife is an external factor affecting the stability, well-being and profitability of businesses that provide a valuable product to our nation and world. Ranchers run viable businesses and depend on the well-being of the land and environmental quality. They enjoy and support a healthy wildlife population and support the historic purpose of wildlife agencies. A balance of man and nature is essential to the well-being of our nation, and this balance must be more clearly defined in order to be obtained. With this balance in mind, people should be allowed to protect their investment and property from outside sources of danger and damage or be fairly and timely

compensated for the damage by responsible parties.

LANDOWNER'S VIEW OF DAMAGE TECHNIQUES AND AGENCY PROGRAMS

Landowners are a very diverse group with very diverse needs and goals. Ranchers are landowners whose businesses depend upon the productivity of the land and will therefore look upon and evaluate damage by wildlife differently than would a homeowner or recreationalist. The opinions expressed in this paper represent some of those of the membership of the Colorado Cattlemen's Association, because it was requested that this paper be written from that approach. Recognize that this is an opinion or viewpoint paper and in no way represents any official position taken by ranchers operating in the United States.

Ranchers and wildlife agencies have been working for many years to find solutions to damage control problems. This long association between agriculture and wildlife agencies has many times been productive and fostered positive working relationships. In other instances, this relationship has been strained. While many agencies and landowners agree on general damage control issues, they have not always agreed on specific control techniques. Input from landowners has been solicited for the development of damage control techniques, but opinions from special interest groups many times has taken precedence over opinions from landowners whose businesses depended upon the land. Therefore, control programs and techniques are sometimes one-sided in their approach and do not always reflect the needs and concerns of ranchers as well as those of the agencies.

Historically, landowners have viewed wildlife damage techniques and programs as ineffective, costly and incomplete, relative to the purpose of controlling damage to personal property and land by wildlife. Rancher's experiences with agency programs have been that they are bureaucratic, restrictive programs that do not meet needs or established goals, but instead treat symptoms in an attempt to solve the problem. Because of restrictions and terms that need to be met with each program, the programs are ineffective in solving the real problem and do not allow for flexibility or creativity in problem solving. In effect, many times the programs are more trouble and hassle than they are worth.

Wildlife agencies are charged with the challenge of meeting a wide range of needs with limited resources and very few useful, effective tools. Many different professionals (ranchers, miners, loggers, etc.) and special interest groups (hunters, environmentalists, recreationalists, etc.) are forced to rely upon wildlife agencies for solutions to their problems. Because agencies are attempting to meet these varied objectives with common programs, the programs escalate in cost, complexity, and implementation time, while decreasing in effectiveness for any specific interest. In essence, agencies are using programs that will pacify everyone's frustrations, while effectively addressing no one's concerns.

While this workshop deals mainly with wildlife damage control, for many ranchers, the best they can hope for is damage compensation. This too, has its drawbacks. Compensation from the responsible party, which in this case is the state or owner of the wildlife, tends to be incomplete, untimely and difficult to obtain. Compensation programs also tend to be one-sided in their approach and implementation.

SPECIFIC PROBLEMS ASSOCIATED WITH DAMAGE TECHNIQUES AND AGENCY PROGRAMS

In dealing with an opinion or viewpoint paper such as this, the only fair approach is to identify specific problems and then offer solutions. From a ranching/business standpoint, the problems with wildlife damage techniques and agency programs are complicated.

"Wildlife damage" can be a very subjective call, for what may be considerable damage from a landowner's perspective may be minor damage or acceptable use to an agency official. Degree of damage is also difficult to quantify and value. The lack of historical information or a basis from which to work makes damage identification and valuation even more difficult and can be a cause of frustration between landowners and wildlife officials. In addition, time lags between damage and discovery may add to the difficulty in quantification or valuation of damage and may make control or compensation all but impossible. Identifying the specific animals or species causing the damage is necessary in controlling the damage and has, in general, also proven to be very difficult and subjective.

Ranchers on the eastern plains report that damage which can be quantified and valued, such as big game getting into haystacks or predator destruction of young livestock etc., is usually controlled or compensated for in a fair and timely manner. On the other hand, they report damage which is difficult to document, such as destruction of wheat fields or grazing land, is not always controlled or compensated for in a fair or timely manner, if at all. Additionally, damage to some forms of property, such as destruction of young trees in a wind break, are not controlled or compensated for in any manner. Nonetheless, many ranchers on the eastern plains report that they do not report damage unless it is extensive or becomes an extreme problem.

Ranchers on the western slope report that wildlife damage control is a much greater problem in their area. They report a great deal of

resistance to claims of damage by agency officials and a great deal of antagonism in receiving legitimate control solutions or fair and timely compensation for wildlife damage, whether it is easily proven or not.

Ranchers operate private businesses that should be treated by the general public as are other businesses - with respect for professional decisions and operations. Nonetheless, because ranchers own and operate on land that is also used by "public" or "state" property (wildlife), their businesses have come under scrutiny by the general public. While ranchers and wildlife agencies may agree that a particular wildlife species is causing damage to personal property or even the environment, public opinion may dictate nothing be done to prevent or control this damage. The issue of wildlife damage has many times become a tradeoff between damage to personal property and control of wildlife, with individual concerns many times losing to public opinion.

Regulations dictate what ranchers as landowners can or cannot do to control wildlife damage. Many ranchers feel that these regulations are so restrictive, and at times illogical, that the purpose is defeated and cost exceeds benefit. Regulations surrounding prairie dog management are a prime example of the control defeating the purpose. Landowner's can only use a limited variety of materials, most of which are highly ineffective in eliminating prairie dogs or the damage they cause and are exorbitant in price. Regulations involved in finding a black-footed ferret, while attempting to control prairie dog destruction of grasslands, have all but eliminated landowner's and agency's ability to control damage by the prairie dog. Again, it appears as if the symptoms are being treated, not the disease.

Wildlife, in-and-of itself, is not the fundamental problem relative to damage; wildlife population is. Obviously, reasonable populations of wildlife keep the ecosystem in balance. Many ranchers welcome the presence of deer, elk, antelope, predators, wildfowl and small game on their land, which add to the quality of their land and lifestyle. Nonetheless, problems do arise when wildlife populations grow beyond numbers that can realistically be supported by the given environment. When this happens, the ecosystem is pushed out of balance and wildlife are forced to rely on additional and/or different forms of nourishment, shelter and water. Existing wildlife damage control techniques and programs do not do an effective job of managing wildlife populations. Instead, they attempt to control specific repercussions of the problem, such as fencing overly large populations of elk out of private hay fields - which has proven to be nearly impossible to do - rather than controlling the elk population in specific.

These problem areas are general in terms and application, but do represent the general feeling of a wide range of ranchers and their diverse operations. It was felt that a specific discussion of individual regulations and techniques would not be productive to this forum.

POSSIBLE SOLUTIONS TO DAMAGE TECHNIQUES AND AGENCY PROGRAM PROBLEMS

In reviewing the problems presented from the rancher's viewpoint, it becomes apparent that a discussion of potential solutions is also necessary. Identification, quantification and proof of wildlife damage needs to be more objective, consistent and obtainable. Establishment of guidelines with the input of landowners would be most beneficial and would assist in building a better working relationship between the two factions. This would also hold true for the valuation of damage and the consistency of the valuation.

Compensation for wildlife damage should be considered a viable option to damage control if that damage cannot be controlled. Because ranching is a business, compensation for damages to that business should be timely, fair and given without unreasonable restrictions or complications.

As discussed, differences exist within the state and most certainly within the region as to the extent, origin, and diversity of wildlife damage to landowner's property. Flexibility of damage control techniques and programs should be incorporated to fit individual or special circumstances.

Regulations for damage control techniques should be simplified so that the real issue of damage control may be addressed and dealt with. Tools and techniques for managing damage by highly destructive but nonetheless protected wildlife species need to be developed or the regulations and restrictions need to be changed so that landowners can protect their property.

The party responsible for damage of private property and the resources on that property needs to be held responsible for that damage. If the state or Division of Wildlife "owns" the wildlife in Colorado that are damaging property and resources, then they should be held accountable for the damage caused by "their" wildlife. The current regulations, techniques and programs do not maintain this position and therefore put the landowner in a poor position to protect their property while protecting the environment and resources vital to the well-being of their families, their businesses and the native wildlife.

Control of wildlife damage needs to be addressed from the perspective of population control. Many programs could be developed that would more effectively control wildlife

populations while meeting the objectives of many groups and individuals. Wildlife "control" or "harvest" hunts could be utilized more effectively in areas where populations have exceeded resources and would satisfy the needs of landowners, hunters, and many hungry families while keeping the ecosystem in balance. Programs could be instigated whereby landowners who work to support and improve wildlife populations would have more input and flexibility with population control. In many cases where specific populations have exceeded resources, such as in the case of prairie dogs, portions of these populations may have to be eliminated. Predator damage is being successfully managed in many areas with the use of guard dogs and these programs should be encouraged and supported by wildlife agencies.

SUMMARY

Ranchers want to be involved in effective wildlife population and environmental management, but do not want to be involved in ineffective, costly programs that do not solve the real problems and are simply a waste of taxpayer's money. It is for this reason that many ranchers do not utilize agency techniques or control programs and do not apply for damage compensation. Nonetheless, they would be very willing to participate in more effective wildlife population and damage control programs. Granted, wildlife population and damage control programs and techniques have been a challenge for many years, but with increased cooperation, and dedication to problem solving and solutions, between landowners, agency personnel, sportsmen, recreationalists and special interest groups, solutions can be found. Wildlife damage comes many times as a result of over-population for a given environment, and it is the responsibility of the aforementioned people to effectively manage these populations so that they can flourish and remain healthy, while in balance with man and his needs.

Effects of Animal Welfare Philosophy on Wildlife Damage Control[1]

Robert H. Schmidt[2]

Abstract.--Wildlife damage prevention and control activities are often criticized when they involve the deaths of wild animals. However, just as the nuclear industry has failed to convince the majority of the public that its industry is safe, education will fail to convince the public that all wildlife damage control techniques are *humane*. Animal welfare-related legislation, university rules on the use of wild animals for research, and litigation are changing the working environment of our profession. This paper reviews aspects of the animal welfare movement as they affect the wildlife damage prevention and control profession and discusses future strategies for living with it.

As wildlife biologists and practitioners of wildlife damage prevention and control, we manipulate wildlife and their habitats. Often, however, what we actually manage are people. Hunting seasons, regulations on trap sizes and shapes, refuge use restrictions, and hunter education requirements are all part of people management.

The people we manage today, along with those whom we do not manage, are not the same as the people managed even ten years ago. Our society is evolving. The general public does not necessarily know *more* than they did a decade ago, but they know *different* things and have been exposed to new ideas. Today, people are familiar with the condition of many elephant (*Elephas maximus* and *Loxodonta africana*) populations throughout the world, and the impact of habitat destruction and poaching on these populations (Booth 1989). People support spending millions of dollars to rescue two California gray whales (*Eschrichtius robustus*) from the arctic ice, even though this species may have recovered to pre-exploitation levels (Aron 1988). Television, radio, newspapers, magazines, and direct mail solicitations expose people to these events (Schmidt 1987*a*). In addition, experiences with wild animals at parks and zoological gardens reinforce the idea that wild animals are harmless, gentle creatures, usually oppressed by humans.

These events and experiences expose people to new ideas. An advertisement for a cage trap for mice is headlined "Must we kill the mouse?" People are taught that farmers and ranchers are affected by a bad case of predator prejudice. Pictures of monkeys strapped in cages reminiscent of Inquisition days question the appropriateness of vivisection. People are told "Let your buying dollar speak for you when you don't buy fur."

In this environment, wildlife damage control and wildlife management are interacting with a skeptical and hostile audience. Wildlife damage control activities in particular elicit strong emotional responses from the public. Few people are neutral. Although people are often sympathetic to losses caused by wild animals, they are not sympathetic to many of the techniques currently used to prevent this damage.

When I attend wildlife damage control meetings and listen to speakers discussing this cultural evolution, I am struck by three things. First, there is usually a very strong "We are right and you are wrong" philosophy expressed, without a logical framework being presented to document this concept. Second, the plan of action to combat these alien philosophies usually involves "educating the public," even though "public" is never defined and specific educational strategies are never proposed. Finally, these presentations are usually the most popular talks at the meeting, judging from the applause and the discussion in the halls during the breaks. From this I can only conclude that the topic is a major concern on people's minds, and that the presentation acts as a "cleansing" to help us face a naive world.

I am being a bit critical, but I want to demonstrate that these presentations are missing the point. Society is changing. The change is inevitable and unstoppable.

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop (Fort Collins, Colorado, April 17-20, 1989).

[2]Robert H. Schmidt is a Natural Resource Specialist, University of California Cooperative Extension, Hopland Field Station, Hopland, CA.

And these changes are affecting the practice of our profession. Animal welfare legislation is proliferating at the local, state, federal, and international level. Today I received notice that the European Parliament supported a Declaration calling for labelling of furs caught with leghold traps. In California, a state in which agriculture is still the leading industry, at least two counties have banned the use of leghold traps. Regulatory actions related to concerns for the environment have led to bans on certain uses of both strychnine and sodium monofluoroacetate (Compound 1080). Institutional Animal Care and Use Committees (IACUC) are questioning the appropriateness of wildlife damage control research. Toe-clipping of rodents for mark-recapture studies is being questioned (Silverman 1989). A recent survey of 95 university and college IACUC chairpersons indicated that only 52% of these committees had at least one member who could be considered a wildlife expert, yet these committees are responsible for judging, among other things, the scientific merits of the studies under review (Bowman 1989). Finally, the enforcement of existing regulations is becoming more strict. The techniques used for the capture of animals or the inappropriate use of chemicals can cause a backlash which affects the entire profession.

Clearly, societal forces *are* affecting what we do and how we do it. These negative responses to our work focus on the materials and techniques we use, the applied nature of our activities (a private party is getting something out of it at the expense of *our* wildlife), and the perceived costs, especially in relation to non-target individuals being impacted and the suffering of target animals.

I like to use an analogy to describe how I think we should face these issues which, I repeat, are not *future* issues but are *present* issues. Picture yourself walking along a beach. On one side is the ocean, its vast expense unbroken by land for as far as you can see. On the other side the beach ends in a towering cliff, which rises vertically from the beach. As the tide rises, running up and down the beach is no help. The water laps at your ankles, then your knees. You struggle to keep upright as the tide tries to tug you out to sea. Swimming won't help because there is no place to swim to. To survive, you have to learn. You have to learn to accept the power of the tide and you have to learn to climb.

Animal welfare concerns are that rising tide. The majority of people have real concerns about *animal suffering*. "Education" won't diminish these concerns and threaten to undermine our current activities (Jones 1988). We, as practitioners of wildlife damage control, have to learn a new skill to cope with animal welfare concerns. Whether we act reactively, proactively, or interactively, we simply need to be active. And I submit that the most successful strategy will be to accept the reality of the animal welfare tide and revise our operations and attitudes accordingly (Schmidt and Bruner 1981, Schmidt in press *a*, *b*).

Our activities should focus on at least two areas. The first is to clean up our act. We need to develop more acceptable techniques and materials. We need to react to public concerns. We need to be honest when we evaluate techniques and materials, even if it involves admitting that leghold traps can cause injury and suffering to wild animals. In short, we need to espouse an "I care" attitude (Richardson 1988).

The other area, in spite of my earlier statements to the contrary, is education. However, I see the need to focus upon the education of ourselves to the public's demands (a marketing strategy to understand the clientele) and upon an educational program to promote a more realistic view of the world to the public. This does *not* involve the "We are right and you are wrong" philosophy, but should be an honest assessment of alternatives, so that the public has enough information to make an informed choice. We can assist the public in seeing both the negative and the positive results of a particular management strategy.

Unfortunately, we may be fighting a losing battle. A survey of 174 wildlife biologists in California, Nevada, and Hawaii indicated that 47% of them devoted 10 hours or less *per year* to conservation education activities (Schmidt 1987*b*). Compare this to the number of animal welfare organizations and activities that exist because of committed volunteers. All is not lost, however. We may not have the numbers, money, and commitment to reach the masses, but we can continue to provide expertise to administrators, legislators, and other decision-makers. Our strategy should include:

- Promotion of a "We care" philosophy,
- Promotion of strategies and materials that reduce suffering (Schmidt in press *a*),
- Active research and testing programs to develop more acceptable alternatives, and
- Continuing education programs to disseminate this strategy.

We, as a profession, should *not* fall into the denial trap of claiming that since suffering is so hard to measure we should ignore it. Pain management and identification in animals is more developed than many of us either know or admit (Fraser 1984, Wright et al. 1985).

We should be the leaders in dealing with these new societal concerns about animal suffering instead of letting legislative, judicial, or regulatory agencies do it for or to us. As we sit in a legislative hearing room, testifying in regards to a leghold trap ban, we enhance our credibility if we can honestly project our concerns about animal suffering, and how we actively promote humane alternatives. With this credibility, we can then describe the need to maintain current tools until that time comes when technology presents us with efficacious alternatives. A similar scenario exists for

testimony before a judge or jury in fighting injunctions to stop wildlife damage control activities.

Is this the "wimp" approach? Are we giving up on our principles? Maybe. I am trying to promote a philosophy of concern for societal principles, morals, and ethics. I am trying to assist in the formation of a healthy and exemplary profession. I am trying to lay building blocks for future change and not stagnation and loss of credibility. Most of all, I encourage debate about all facets of the animal welfare issue.

It should be obvious that I have avoided reference to the animal rights movement. The animal *rights* philosophy, which promotes the concept that animals have rights analogous to human rights, is not the same as the animal *welfare* philosophy (Schmidt in press *a*, *b*), which promotes the reduction of animal suffering. It is a vocal but minority movement, and will need to be addressed in the future.

We are not inherently "bad" people, torturing animals for the fun of it. We are working to save livestock from predators, corn from blackbirds, people from rat-borne diseases, and jet aircraft from bird strikes. Simultaneously we attempt to avoid negative impacts on non-target organisms, minimize the use of pesticides in the environment, and remain concerned about endangered species, pets, and public health and safety. We now need to add an additional element to our activities, and that is concern for the reduction of animal suffering in wildlife damage control activities. Let us do so before somebody tells us we have to do it. Let us do so because we can live with it. Let us do so because it is the right thing to do.

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Estimating Domestic Sheep Losses to Mountain Lions[1]

Frederick G. Lindzey and Connie Wilbert[2]

Abstract.--Large, native-range pastures were searched for dead domestic sheep in the Southern Bighorn Mountains of Wyoming. The proportion of dead sheep that had been killed by mountain lions was 23%. Search methods, however, resulted in unequal probabilities of finding sheep that were killed by mountain lions and sheep that died of other causes.

INTRODUCTION

Mountain lions (Felis concolor) will kill most species of domestic livestock although sheep and cattle occur most commonly in depredation incidents. Cattle losses are highest in Arizona and New Mexico with the frequency of depredation problems involving cattle generally decreasing northward in the mountain lion's range (Shaw 1979). Shaw felt that this phenomenon largely could be explained by husbandry practices; losses are greatest where calves are born in mountain lion habitat. Sheep, on the other hand, appear to be killed anywhere they graze in areas occupied by mountain lions with lambs being killed more often than adults. It is common to have more than 1 sheep killed in a single incident (Sitton 1978, Bowns 1984); 59 sheep were killed in 1 night in Nevada (Suminski 1982).

Nation-wide, sheep losses to mountain lions appear small enough to be of little economic importance. For example, Suminski (1982) determined that average losses of range sheep to mountain lions in Nevada averaged only 0.29 percent. Not all woolgrowers share these losses, but rather, a few sustain heavy losses which can have a severe impact on their operations.

Historically, the potential for depredation resulted in widespread mountain lion control and eradication programs. When states began to assume management authority for mountain lions in the 1960's (Nowak 1976), management programs included very liberal depredation provisions aimed at allowing livestock owners to protect their animals. Although states currently vary in their approach to the problem of mountain lion predation on domestic livestock, all include some provisions in their management programs that address this problem. Wyoming is one of 2 states that reimburses owners for livestock killed by mountain lions (Bowns 1984). Wyoming Statute 23-1-901 stipulates that the Wyoming Game and Fish Department "investigate and allow payments for damages to livestock caused by trophy game animals."

Problems encountered in Wyoming in reimbursing livestock owners for animals killed by mountain lions are twofold. First, there are, and likely always will be disagreements over cause of death of individual animals. Secondly, woolgrowers wish to be reimbursed not only for sheep that are documented as killed by mountain lions, but sheep that are not accounted for and that may have been killed by mountain lions. There is general agreement that some of the sheep that do not return from summer pastures are likely to have been killed by mountain lions, but significant disagreement on the proportion of lost sheep attributable to mountain lion predation. The literature provides little assistance in resolving this problem. Studies that have quantified loss of sheep to predators have typically not been done in areas where mountain lions were expected to be a major predator (Klebenow and McAdoo 1976, Nass 1977, Tigner and Larsen 1977, Taylor et al. 1979). Shaw's (1977) work in Arizona, although probably the best investigation of mountain lion predation on livestock, dealt with cattle. Bruscino and Norelius (1987) studied cause-of-death of domestic sheep in the southern Big Horn Mountains of Wyoming and provided the first insight into the potential impact of mountain lions on sheep herds in this region. Their results indicated that 27% of the dead sheep found had been killed by mountain lions.

The primary objective of this study was to locate and determine cause of death of dead domestic sheep on pastures on the east slope of the southern Bighorn Mountains. Secondarily, we wished to evaluate whether our sampling approach provided a representative sample of dead sheep.

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Study Area

The study was done on the east slope of the southern Bighorn Mountains in Johnson County, Wyoming. Searches were conducted within large, native-range pastures grazed by domestic sheep. Pastures varied in the amount of cross-fencing present and thus the degree to which sheep movements were controlled. Pastures are largely privately owned although some grazed areas are leased from the Bureau of Land Management.

Elevation ranges from 1980 to 2500 m. At lower elevations mountain mahogany (Cercocarpus ledifolius) and Utah juniper (Juniperus osteosperma) are interspersed with areas of sagebrush (Atremisia spp.) and open grasslands. Numerous small, dry canyons and several large, deeper canyons run east and west through the area (Bruscino and Norelius 1987). Higher elevations are dominated by mixed stands of ponderosa pine (Pinus ponderosa) and younger stands of limber pine (Pinus flexis). Common juniper (Juniperus communis) is abundant in the understory of dense conifer stands. Small quaking aspen (Populus tremuloides) and lodgepole pine (Pinus contorta) stands occur occasionally in the higher elevations that are dominated by grasslands. The area contains vegetation and topography preferred by mountain lions (Logan and Irwin 1986, Laing 1988).

Timing of grazing on the pastures is largely determined by weather. Sheep are typically trailed onto the mountain after shearing and docking in late May and early June. Although not generally herded, they are visited regularly for inspection. Sheep are trailed from the mountain in October or November depending on snowfall.

METHODS

Pastures were selected for inclusion in the study based on several factors. These included: 1) the willingness of owner-operators to cooperate in the study; 2) proximity to other study pastures; 3) historical level of mountain lion depredation problems; 4) vegetation and topography representative of the southern Bighorn Mountains and; 5) access.

Search blocks were about 130 ha in size. Location of blocks in the pastures was based on spatial use of the pasture by the sheep since the previous search as indicated by reconnaissance of the pasture and or discussions with the owner-operator. Each search block was oriented to include a representative sample of the vegetation and topography in the area used by the sheep. Transects were spaced at 91.4 m intervals within the block and generally oriented across the shortest dimension of the block. Transects were followed using an orienteering compass. Search block locations and transect starting points were identified by distance pacing and topographic features. New search blocks were identified each time a pasture was returned to.

Transects were walked or ridden on horseback by either 1 or 2 observers. When walked or ridden by only 1 observer, every fifth transect was walked again in the opposite direction. Only carcasses judged to be from the 1988 grazing season were included in analyses. Presence or absence of wounds or tooth marks, predator sign, stage of decomposition, sex and age and position of the carcass were noted. Slope, aspect, topography and vegetation type were determined for the carcass site and surrounding area. Distance at which the carcass was first seen, its perpendicular distance to the transect line, and the distance it could be seen from the 4 cardinal directions was measured. Each carcass found was marked with red paint and a numbered tag.

Cause of death for each carcass was determined based on a key. The key was developed from information in the literature (Shaw 1987, Bowns 1976) and suggestions from persons experienced in animal damage control, and reviewed by ranchers and Wyoming Game and Fish Department (WGFD) personnel. Our intention was simply to determine if a sheep had been killed by a mountain lion or not.

Transects were generally double sampled by the first observer flagging the route and the second observer following the flagged transect and retrieving the flags. Each carcass found by either observer was investigated as described above. Carcasses were painted only on the underside by the first observer to prevent it being detected by the second observer because of the paint marking.

RESULTS

Four pastures, averaging 1830 ha in size, were included in the study (table 1). Nineteen search blocks were sampled; 32% were double sampled (table 2). The first search block was sampled in mid-June; the last block was sampled in mid-October 1988. Ten percent (n=18) of the transects in the single sampled blocks were walked twice by the same observer. Fifty-two sheep carcasses were found (table 3). Twelve (23%) of these sheep were killed by mountain lions. Sixty percent of all carcasses found (n=31) were lambs; all sheep killed by mountain lions were lambs. Sex of the dead lambs was determined for only 29% of the carcasses (6 males, 3 females).

Sheep killed by mountain lions were found in areas of dense conifer overstory, sage-grass and

grass vegetation types (table 4). Sheep that died of other causes were found in all vegetation types except those dominated by a conifer overstory. Carcasses of sheep killed by mountain lions were visible from the 4 cardinal directions at significantly shorter distances than carcasses of sheep that died of other causes (t=19.3 df=188) (table 5). This difference was most obvious in sage-grass and grass vegetation types (t=-6.14 df=78, t=5.38 df=106). Although dead sheep were found on slopes up to 40 degrees, most (88%) were located in areas ranging from level to 20 degree slope.

Table 1.--Pasture size, stocking level and percent of sheep missing the after grazing season on the Southern Bighorn Mountains, Wyoming.

Pasture	Size(ha)	Sheep[a]		% loss[b]
1	809	Ewes	1345	8
		Lambs	1074	3
2	1619	Ewes	1468	3
		Lambs	1710	4
3	3173	Ewes	1523	2
		Lambs	1003	8
4	1716	Ewes	1217	6
		Lambs	880	13

[a] Number of sheep on pasture
[b] Percent of sheep reported as missing by operator after grazing season.

Table 2.--Number of search blocks and transects sampled for dead domestic sheep in the southern Bighorn Mountains, Wyoming (June-Oct. 1988).

Pasture	Search blocks	Transects
1	6 (2)[a]	63 (79)[b]
2	4 (1)	38 (48)
3	5 (2)	34 (63)
4	4 (1)	36 (45)
Totals	19 (6)	173 (235)

[a]Number double sampled.
[b]Kilometers of transects. Does not include double sampling or back-walking transects.

Table 3.--Dead domestic sheep found and cause of death of these sheep on the east slope of the southern Bighorn Mountains, Wyoming 1988.

Pasture	Mountain lion	Other causes	Totals	% of loss[a]
1	0	14	14	10
2	7	16	23	21
3	0	3	3	3
4	5	7	12	7
Totals	12	40	52	9.4

[a]Percent of the sheep reported as missing by operators found on transects.

Table 4.--Vegetation types in which domestic sheep carcasses were found on the east slope of the southern Bighorn Mountains, Wyoming (1988).

	Mountain lion		Other causes	
	No.	%	No.	%
Conifer	2	17	0	0
Dense sage	0	0	2	5
Sage-grass	3	25	17	42
Mahogany-grass	0	0	1	3
Grass	7[a]	58	20	50

[a]Four of these carcasses were found together on the same bedground.

Only 1 carcass of a lion-killed sheep was intact, while 20 carcasses (50%) of sheep that died of other causes were whole when found. Intact carcasses of sheep that died of causes other than mountain lion predation were visible at significantly greater distances (x=30.6 m s.d.=30.5) than those that were scattered (x=16.3 s.d.=21.3, t=-2.8 df=106). Eighteen of the carcasses of sheep that died of causes other than mountain lion predation, and not found intact, had been fed upon by other animals. Over half (58%) of the carcasses were first detected by seeing the carcass itself, 19% by first detecting wool fragments, 12% by finding bone fragments, 10% by smell and 2% (n=1) by seeing a scavenger at the site.

Only 1 additional sheep carcass was found on the transects that were walked a second time by a single observer. Two of 11 sheep carcasses were found by only 1 of the 2 observers during double sampling efforts. The 2 sheep that were found by only 1 observer died of causes other than mountain lion predation. These carcasses were found in grass and sage-grass habitats, initially sighted at 6.4 and 11 m. and were visible from 26.2 and 21 m respectively.

Table 5.--Mean distance in meters (s.d.) that dead domestic sheep were visible in differing vegetation types on the east slope of the Bighorn Mountains, Wyoming (1988).

Veg. type	Initial sight[a]		Cardinal dir.[b]	
	Mt. lion	Other	Mt. lion	Other
Confer	8.4[c]		7.8(4.8)[c]	
Dense sage		8.5[c]		9.8(10.5)
Sage-grass	2.0(0.9)[c]	53.3(73.8)	3.4(2.2)	42.6(50.9)
Mohogany-grass		3.1[c]		24.8[c]
Grass	22.1(6.8)	39.8(64.6)	33.9(17.4)	41.2(60.9)
Totals	14.1(10.4)	42.5(90.7)	22.2(19.9)	36.8(54.7)

[a]Distance carcass initially sighted from.
[b]Average distance carcass visible from 4 cardinal directions.
[c]Small sample size (n<5).

DISCUSSION

Fewer dead sheep were found this year than found last year by Bruscino and Norelius (1987) in the Southern Bighorns (52 vs. 77) and a slightly smaller percentage was attributed to mountain lion depredation (23% vs 27.3%). Proportionately fewer lambs (60% vs 75%) occurred in the sample in 1988 than in 1987. The smaller number of sheep examined may be due, in part, to the fact that only half the number of ranches was surveyed this year. Reported average loss of sheep on the 4 pastures was 6%, but ranged from 4 to 9% compared to an average loss of 8.3% reported by Bruscino and Norelius (1987).

Our data support Bruscino's and Norelius' findings that few sheep which die of causes other than predation are found in timbered areas. The proportion of all lion-killed sheep found in timber was 17% this year and 19% last year. Most sheep that die of causes other than mountain lion predation, on the other hand, were found in sage or grass habitats.

The reduced visibility of carcasses of sheep killed by mountain lions probably resulted from a number of causes. Proportionately more carcasses of lion-killed sheep were scattered than were carcasses of sheep that died of other causes, and intact carcasses were detected at significantly greater distances. Secondly, carcasses of lion-killed sheep appeared to be found in areas of denser vegetation even within the same vegetation type.

Differential visibility of carcasses in the various vegetation types and the tendency for lion-killed sheep to be detected at shorter distances are 2 identified forms of bias that may influence the degree to which the sample of dead sheep we found is representative of all the sheep that died during the grazing season in these pastures. Although, by design, our transects traversed vegetation types in proportion to their occurrence in the search blocks, because of differential visibility, the area actually searched in each vegetation type was often not proportional to its occurrence in the search block. The potential for bias in the sample occurs because the proportion of lion-killed sheep appears to differ with vegetation type. The difference in detectability of sheep killed by mountain lions and those that died of other causes presents a similar problem. Due to the spacing of transects (91.4 m), we effectively searched less area for lion-killed sheep than we did for sheep that died of other causes.

Paying for sheep that are not documented, but possibly killed by mountain lions presents numerous problems. Differences in opinion on the proportion of missing sheep killed by mountain lions will be common and the proportion of lion-killed sheep will likely differ between years and pastures. Formulas to determine the proportion of missing sheep killed by mountain lions will need to reflect the uniqueness of years and pastures if they are to gain general acceptance. If samples of dead sheep are to be used in formulas to determine numbers of lion-killed sheep, sampling schemes must be designed to avoid biases such as those we identified.

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Evaluating Mountain Lion Depredation of Domestic Sheep[1]

Mark Bruscino[2]

Abstract.--In 1987, 171 domestic sheep (Ovaris aires) killed by mountain lions (Felis concolor) were examined in the Bighorn mountains of north-central Wyoming. Lions typically killed the sheep by attacking the head or neck regions. Feeding usually started with entering through the brisket and consuming the heart, lungs and liver. Feeding continued with the leg bones sheared above the hock and knee. Most of the carcasses that were moved by the lion were found in shrub or timber type vegetative habitat and in relation to rimrock topography.

INTRODUCTION

The Wyoming state legislature reclassified mountain lions from predator to trophy game status in 1973. The change in classification transferred management responsibility from the Wyoming Department of Agriculture to the Wyoming Game and Fish Department. Since 1981 the Wyoming Game and Fish Department has been responsible for reimbursing stockmen for livestock killed by mountain lions. From $6,858.30 to $55,717.70. Although the majority of the claims have been for losses of domestic sheep, depredation claims for cattle and horses have increased as well.

The Wyoming Game and Fish Department personnel are responsible for determining the cause of death of livestock claimed to have been killed by lions. It has become necessary to be able to accurately evaluate livestock losses to equitably reimburse the stockmen and responsibly manage the department's damage fund.

STUDY AREA

Research was conducted in Johnson and Washakie counties in the southern Bighorn Mountains of north-central Wyoming. The area is a mixture of private and public lands used primarily for pasturing livestock in the summer. The southern Bighorn Mountains is the largest sheep producing area of the state.

Due to winter snow conditions, livestock grazing is restricted to June through early November. Most sheep operations consist of large fenced pastures. The sheep are not herded and are selected to scatter throughout the pastures to equally use the range. The sheep are generally found in the open grass areas for shade during the warmest part of the day. Sheep are rarely found in the rougher terrain due to poor habitat conditions and natural barriers.

Elevations in the area range from 4500 ft. to 8200 ft. above sea level. The area is characterized by open gentle slopes traversed with frequent small canyons and rimrocks. Several large, deep canyons highlight the topography.

MATERIALS AND METHODS

Two search plots were chosen on each of eight ranch operations ranging in size from 249 to 6094 sheep at docking. Ranches and plots were chosen based on historical depredation incidences or suspected problem areas. Search plot ranged in size from 160 to 500 acres depending on the difficulty to inspect the area. An attempt was made to search each area as thoroughly as possible for dead animals. North-south and east-west routes were traveled on successive days for each study plot. Searches were conducted on horseback and foot. In addition, all carcasses in the southern Bighorns reported by stockmen or incidentally discovered by department personnel were also included in the sample.

When a carcass was located, the immediate surrounding area was searched for signs of predators in the form of scat, scratch piles or tracks. Indicators that the animal had been moved, scavenger sign and carcass position were noted. Carcass location, distance to cover, and if the animal was covered was recorded. Stage of decomposition, location and type of external injury, and areas fed upon were examined.

A field necropsy was performed to locate and document subcutaneous trauma, internal trauma, and skeletal fractures. Puncture wounds spacing from canine teeth were measured.

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. (Fort Collins, Colorado, April 18-19, 1989).

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RESULTS

During the 1988 field season 329 domestic sheep carcasses were examined by department personnel. Fifty-eight were discovered during structured ground searches, 17 were located incidental to other field duties and 96 were reported by landowners. Of the 329 sheep evaluated, 171 were determined to have been killed by mountain lions. Of the 171 sheep killed by mountain lions, only nine (5.3%) had lion sign in the form of scat or tracks associated with them. Three (1.7%) of the nine had discernible lion tracks nearby. Six (3.5%) had fresh lion scat within 140 ft. of the carcass location. Laboratory analysis found that all six samples had contained domestic sheep wool.

Thirty-one (18.1%) of the sheep carcasses had evidence that the cat had attempted to move the kill. When the lion did move the carcass, 23 (74%) were moved to areas that provided additional vegetative or topographic cover. Of all the sheep killed, 89 (52.1%) were found in shrub type vegetative habitat, 46 (26.9%) were located in grassland habitat. The remaining 36 (21.1%) were located in timber stands. A significant portion (p .001), 138 (80.7%) were located in rimrock or canyon type topography, while the remaining 33 (19.3%) were killed on flat or gentle slopes. More than one-third (36.4%) of the lion-killed sheep were found in areas of topographic or vegetative cover thought to be adequate for lion concealment and movement. 139 (81.4%) were located within 160 ft. of cover suitable for lions. In only 11 (6.5%) instances did the cat attempt to cover the kill. Covering was usually done with pine needle litter scraped from the immediate surrounding area.

Of the 171 lion kills, 152 (88.8%) showed evidence of biting on the dorsal or lateral portions of the neck or skull. When adult sheep were bitten on the skull, canine teeth usually caused puncture wounds to the cranium caused by the canine teeth. A bite to the skull of a lamb often resulted in fracturing at the sutures or a crushed skull. In most instances there was evidence of only a single bite indicating death by strangulation, spinal cord damage or hemorrhage. In 33 (19.3%) of the lion kill, the sheep incurred fractures to the cervical vertebrae. Significantly (p .001) more lambs (25) had fractures to the cervical vertebrae than did ewes (8).

Eighty-nine (52.1%) sheep had some evidence of feeding, although only 12 (7.0%) had been completely consumed excluding the hide and some skeletal components. Lambs comprised 10 (83.3%) of the sheep fully consumed. All consumed carcasses were found in relation to topographic or vegetative cover. Initial feeding was usually through the brisket region with a portion of the ribs eaten away to allow access to the heart, lungs, and liver. The rumen was often removed and covered several feet away from the feeding site. Feeding typically continued with the striated muscle from the ventral portion of the front quarter or hind quarter eaten while the hide was peeled back. Often one up to all four leg bones were sheared cleanly through above the knee and hock.

DISCUSSION

Although evidence associated with mountain lion depredation of domestic sheep seems to vary, this study found that there are indicators that can be compiled that will point to lion depredation. Tracks were often difficult to discern due to firm soils and exposed bedrock in the area. Lions do not seem to mark their kills with scat or scratch piles on a regular basis. Lions tended to move the carcasses if they were killed in an area unsuitable for concealment while feeding. Oftentimes, carcasses were abandoned where they were killed with little or no feeding which indicates that they have very poor use of the prey item, or they do not always kill for food.

The significant portion of sheep found in relation to topographic or vegetative cover suggests that lions will not venture far from cover to pursue sheep. Wade (1929) and Van Pelt (1977) found that lions use cover to stalk and attack prey. Sheep are found in this type of habitat usually only during the middle of the day or occasionally bed in that type of habitat at night. It is then likely that most attacks take place during daylight hours. This study found that there was a relationship between habitat selected by sheep and vulnerability to lion attacks. When the sheep remained in large open pastures, the rate of attack was less than for sheep using areas with more cover.

Covering of the carcass seems to occur when lions intended to return to feed as most abandoned kills had no evidence of being covered. The cat will generally recover the carcass after each feeding until they do not intend to return. The majority of the kills were neither covered, cached nor fully consumed.

Sheep appear to be easy prey for lions as there was rarely sign of a struggle. Most sheep were killed with a single bite to the neck or head. As carcasses decompose, evidence of cause of death is lost. Tooth marks in the forms of punctures, grooves, scrapes or fractures to the cervical vertebrae are often indicators in advanced stages of decomposition, although they do not always occur. This study is supported by finding by Nowak (1976) that lions kill by severing the spinal column, breaking the neck, or crushing the skull. Lambs suffered cervical fractures at a higher rate than did adult ewes, likely due to less muscle tissue protecting the vertebrae. Lambs were killed at a higher incidence, likely due to vulnerability.

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Trophy Game Animal Damage in Wyoming[1]

Ron Iverson[2]

Abstract: Wyoming is perhaps one of the most liberal and unique states of the fifty states on compensation for game and trophy game animal damage. Trophy game animals as defined by statute in Wyoming includes the Cougar (Mt. Lion), Black Bear, and the Grizzly Bear. According to statute Wyoming is responsible for damages incurred by these species to livestock, land, crops, improvements, and extraordinary grasses. Since the statutes were enacted Wyoming has been faced with a variety of complaints and damage claims caused by these species. Damage complaints received by the Department have covered a broad spectrum, ranging from the stockman losing livestock to the everyday housewife with a black bear coming onto her back porch to eat the dog's food.

This paper illustrates methods, budgetary requirements, and manpower that the Wyoming Game and Fish Department uses to alleviate or reduce damage, investigate complaints, and to compensate for damages incurred by trophy game animals in Wyoming.

Let me start with a brief summary of the makeup Wyoming Game and Fish Department and what some of the requirements are to hold a Damage or Game Wardens position. The Wyoming Game and Fish Department is presently controlled by a seven member board appointed by the state's governor. This board is known as the Wyoming Game and Fish Commission. We have five divisions within the Department; Game Division, Fish Division, Information and Education Division, Fiscal Division, and the Habitat and Technical Services Division. The Game Division, which has the responsibility of handling all aspects of terrestrial wildlife, is comprised of seven districts that are located throughout the state. The districts vary in size from about 8,000 square miles to about 24,000 square miles. Each district has one damage control warden, an average of seven game wardens, one enforcement specialist, three biologists, one biologist coordinator, and a supervisor.

The damage control warden, the game wardens, or the supervisor handle the damage calls for the District and can be notified about any wildlife depredation, which includes Trophy Game Animal damage. The responsibility of prevention and investigations falls mainly on the damage control warden or the game warden assigned to that area. Those responsibilities include wildlife damage prevention and investigations of (big game, trophy game, and game birds), wildlife law enforcement, game management, and public relations. The requirements to become a damage warden or a game warden include a four year degree in wildlife management, biology, range management, or other fields that are related; and must successfully take and pass the game wardens exam. Once hired he must complete the basic training course at the Wyoming Law Enforcement Academy.

The district which I am responsible for is one of the smaller districts in the state with a little over 8,000 square miles. There are five wardens and one damage control warden to handle damage complaints and investigations. The district has a wide variety of terrain, ranging from high desert ecosystems to alpine systems in excess of 13,000 feet elevation.

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[1]Paper presented at the Western Plains Damage Workshop, April 16 - 20, 1989, held at Colorado State University, Ft. Collins, Colo.

[2]Ron Iverson, Damage Control Officer, Wyoming Game and Fish Department, Lander, Wyo. 82520

All big game species are present with the exception of mountain goats which are only found in the northwest corner of the state. All three trophy game species, mountain lion, black bear, and the grizzly bear are located in the district. In 1973 Wyoming State Statute 23-1-101 was recodified to add the mountain lion with the black bear, and the grizzly bear as trophy game animals, up to this time the lion was designated a predator. This meant that the Wyoming Game and Fish Department was assigned the responsibility to manage the lions as well as both species of bears. It also meant that the department was responsible for damage incurred by these species to land, crops (cultivated, standing, or stored) improvements, and extraordinary damage to grasses. In 1980 the statute was changed again to include damage incurred by trophy game animals to livestock. The department became liable for payment when a trophy game animal damaged or killed livestock.

Indications are that bear and lion populations throughout the state have been increasing since use of 1080 was banned and grizzly bears achieved threatened status in 1975. Although the grizzly bear is protected under the Endangered Species Act the department is still responsible for the damages caused by grizzlies. With increasing populations our department has realized a corresponding increase in the number of complaints and the number of claims received regarding trophy game animal damage. With these increases, the cost of maintaining these species dramatically increased.

TABLE A-1

MOUNTAIN LION

YEAR	*MAN DAYS SPENT	**LIONS HARVESTED	***MANAGEMENT COST	COST/LION HARVESTED
1981	101.5	18	$180,328	$10,018.22
1982	103.5	21	$363,948	$17,331.86
1983	142.0	37	$232,238	$ 6,276.70
1984	67.0	39	$ 77,695	$ 1,992.00
1985	136.5	56	$189,861	$ 3,390.00
1986	117.0	63	$166,518	$ 2,643.00
1987	138.0	50	$276,806	$ 5,777.00
1988	164.0	102	$264,450	$ 2,593.00

*Man-days spent are days attributed to lions damage prevention, investigation and nuisance wildlife control.

**Lion harvest reflects all kills including removal of problem lions by the Department.

***Management costs are all costs attributed to lions except damage claim payments.

The Department annual reports from 1981 to 1988 illustrates maintenance cost to the department by species, (Tables A1-A3).

TABLE A-2

BLACK BEAR

YEAR	*MAN DAYS SPENT	***BEARS HARVESTED	**MANAGEMENT COST	****COST/BEAR HARVESTED
1981	44	408	$215,137	UNKNOWN
1982	91.5	236	$229,477	UNKNOWN
1983	95	348	$541,919	UNKNOWN
1984	11	300	$556,131	$1,854.00
1985	31	267	$ 53,280	$ 199.55
1986	45	232	$ 68,176	$ 293.86
1987	68	331	$ 78,462	$ 237.00
1988	101.5	289	$ 80,998	$ 280.00

*Man-days spent are man days attributed to nuisance control, damage investigations, and damage prevention.

**Management costs are those costs attributed to black bear management. These costs don't include damage claim payments, (Table A-4).

***Bears harvested are only those bears taken legally by hunters and doesn't include illegal harvest or nuisance bears.

****Unknown costs/bear harvested from 1981-83 can't be figured because management costs for grizzly was combined with the black bear.

TABLE A-3

GRIZZLY BEAR

YEAR	*MAN DAYS SPENT	**GRIZZLY HARVESTED	***MGMT. COST	COST/GRIZZLY HARVESTED
1981	0	PROTECTED	$ 215,137	NONE
1982	0	PROTECTED	$ 229,477	NONE
1983	0	PROTECTED	$ 541,919	NONE
1984	11	PROTECTED	$ 498,440	NONE
1985	59	PROTECTED	$1,386,570	NONE
1986	6.5	PROTECTED	$ 542,640	NONE
1987	12.5	PROTECTED	$ 490,259	NONE
1988	4.0	PROTECTED	$ 677,608	NONE

*Man-days are days attributed to days spent on nuisance control, damage prevention and investigations. From 1981-1983 man days were combined with black bear man days.

**Grizzly harvest indicates bears harvested legally, it doesn't reflect illegal harvest or problem bear harvest.

***Management costs from 1981-83 were combined with black bear management cost. Management costs only reflect cost by the department to manage the grizzly, they don't reflect the cost of damage claim payments.

TABLE A-4

DAMAGE 1981-1989

SPECIES	DAMAGE CLAIMED	DAMAGE PAID	*NUMBER OF CLAIMS
Mountain Lion	$455,770.01	$312,786.43	235
Black Bear	$ 34,428.59	$ 26,042.46	53
Grizzly Bear	$ 2,121.33	$ 2,121.33	2

*Reflects only damage claims submitted for payment, damage complaints aren't included.

As you can tell from these charts maintenance costs rose to the highest levels in the mid 1980's and then dropped but now again have started to raise. Not included in these costs are costs of damage claim payments, (Table A-4). Funding to pay Trophy Game Animal damage as well as Big Game and Game Bird damage comes from a five dollar application fee collected on all nonresident big game license applications. This fund has a $500,000 ceiling on it at which time the moneys are deposited into the general Game and Fish Fund and used for other projects. The dollar amounts paid for damage compensation have risen over the last few years to where in the foreseeable future payments will exceed the limit, at which time other funding will have to be provided.

There are several methods, (from repel collars on livestock to ole shep staked out on the back porch), to reduce or to prevent damage by trophy game animals. The ones I've found to be most manpower and cost effective include: 1.) manipulation of hunting seasons, 2.) manipulation of grazing practices, 3.) trapping and transplanting, 4.) and as a last resort, removal from the population. An example using hunting seasons to reduce trophy game animal damage can be demonstrated using two lion areas in the state. These two areas are in the central part of the state, they have real good populations of wildlife (mainly deer), and have terrain and habitat ideal for lions. Domestic sheep are the primary animals raised by the livestock producers in the area. The lion damage was out of control, mainly to sheep on summer range. Several types of seasons and kill quotas were tried, but what seemed to work best was a year around season with all the kill quotas lifted. This seemed to reduce the damage to where it satisfied the livestock producers. The population of lions in those two area are believed to have decreased.

The Wyoming Game and Fish Department has effectively worked with landowners, National Forest Service, Bureau of Land Management, the University of Wyoming, the Fish and Wildlife Service and the Park Service to change or trade allotments or alter grazing practices to reduce conflicts with wildlife. Some examples are changing the allotments from sheep to cattle or trading vacated allotments to reduce conflicts. These allotments aren't always changed or traded solely for a damage reason, but often times damage conflicts are taken into consideration. In the case of the grizzly some areas have been set aside where the priority is for the bear. These areas are classed as Situation I Grizzly Bear Management Areas and are part of the Yellowstone Ecosystem that is adjacent to Yellowstone National Park. In these areas if conflicts occur the lessee may be asked to move his livestock either to another allotment where conflicts won't arise and a vacated one is available or completely out of the area ... I think that trapping and transplanting is probably the method most used in my District. Most cases involve bears, although some lions have been relocated, from unwanted places like campgrounds, urban areas, livestock allotments and hunting and fishing camps in the back country. It's just a matter of live trapping or tranquilizing the animal and moving it to a location where conflicts won't be as likely. Some of the draw backs of this method are: 1.) it isn't a fail safe method as you might be creating problems somewhere else and the Department has relatively no information of the displacement of the resident animals of the area. 2.) also the problem might occur in an area that is inaccessible with a trap and helicopter, transportation might not be cost effective, I'm sure all departments are watching their budgets. 3.) reaction time might be hampered by involvement of too many agencies as in the case of the grizzly. This brings us to the last resort method which is to destroy the animal. Once the animal has been destroyed it can be used for research, education, exhibits and displays, or hides and skulls can be sold at auction to generate revenue. As in the case of relocation there are exceptions with the grizzly bear. Before any grizzly is destroyed certain things are taken into consideration by the U.S.F.W.S.. If the nuisance grizzly meets the criteria to be destroyed it becomes the property of the Federal Government.

Wyoming's State Statute 23-1-901, says that a person that has damage has 15 days from the time the damage is discovered to report it to a damage control warden, game warden, or a supervisor. By commission policy the Department has three days to initiate an investigation. Investigations of damage caused by trophy game animals can vary from looking at dead sheep - to looking at a bunch of bee hives that are scattered about with mad bees everywhere - to confronting a lady that a bear had just wondered into her house to get ole shep's dog food - to confronting that back country woodsmen with his shredded tent.

Whatever the case may be the most important thing to determine is what actually caused the damage.

Often times bears and lions are blamed for damage that is really caused by other animals such as racoons, coyotes, feral dogs, bobcats, or foxes. Poisons, lighting, and natural causes may also be responsible. A bear or lion on a kill or in the immediate area is not sufficient proof the animal was the cause of the damage. Tracks, geographical locations and scat (unanalyzed) are good indicators of the cause but are not absolute. Bite marks, scat (analyzed), and necropsies are better indicators.

After determining what has caused the problem the next step is to determine how much damage has occurred. In the case of livestock losses actual counts are used. However Wyoming does have certain areas of the state designated as special compensation areas for lion damage to livestock. In these areas the Department will offer for settlement of lion damage claims, a formula based on a study conducted by the department. It states that lion damage settlement will equal confirmed kills plus .27 x total numbers of missing ewes plus .28 x the total numbers of lambs. Total numbers will be determined by shearing counts, docking counts, shipping counts, lamb counts, landowner or lessee counts, lending institution counts, brand inspectors counts, trailing permit numbers, counts based on wool incentive programs, tax records, or combinations of any of the above. This technique recognizes the Department's inability to find all sheep killed by lions and recognizes that all sheep not found were killed by a lion. This plan is in effect on a one year trial basis. In both cases payment is based on current market value. Another type of damage encountered usually with bears is property damage i.e. improvements. According to 23-1-901, the Game and Fish Department is also responsible for damage to improvements. Improvements according to the dictionary are "a change that improves or adds value to something". What it doesn't explain is in whose eyes. So we've looked at everything from camping equipment to furniture to bee hives to show dogs. I guess the hardest part is trying to figure out what things are worth and then reaching agreement with the claimant. As strange as it may seem we have also investigated crop damage by trophy game animals as our law prescribes cultivated, standing and stored crops. Some examples that I'm familiar with are bears in apple orchards, bears in camps eating grain and horse cake, bears in gardens eating vegetables, bears in bee hives eating honey, and bears in barns and granaries eating cake and grain.

After the investigation has concluded and all attempts have been made to prevent ongoing damage and the damage quits or has reached a level that the claimant can live with, a Damage Claim Affidavit (Figure A-1) can be filed within 60 days to the office of the Chief Game Warden.

Figure A-1

G-20A 1988

BIG GAME ANIMAL AND/OR GAME BIRD
DAMAGE CLAIM AFFIDAVIT

STATE OF WYOMING)
)
COUNTY OF ____________)

I, ______________________ of ______________ (insert mailing address)

______________________, being of lawful age and being first duly sworn upon oath depose and say:

That I am the landowner, lessee or agent (circle one) of the following described property in the county of ______________, State of Wyoming, which was damaged by big game animals and/or game birds (circle one or more applicable) of the State of Wyoming, to-wit: (Insert here legal description of said property and specify whether owned in fee or leased. If leased, specify whether Federal, State or private)· ____________

That the damage was caused by big game animals and/or game birds (circle one or more applicable) commonly known and referred to as (here indicate type and approximate number):

That the damage for which this Affidavit of Claim is made was discovered on the following date and ended on stated date: (Here insert the date of damage for each specific item of damage claimed. If part of damage involves a series of depredations, specify date begun and date ended. A verified claim for damages must be presented at the office of the Commission not later than sixty (60) days after the damage or last item of damage)·

That said damage amounts to the total sum of $____________, which includes the following items of damage and is computed as follows: (Here specify each item of damage claimed: description of the damaged land, growing cultivated crops, stored crops, seed crops, improvements and/or extraordinary damage to grass):

The property is___, is not___, partially___protected. If so how?____________

The landowner allows hunting___, prohibits hunting___, charges access fees________ guides hunters___, denies access___, other____________

It is recommended this claim be paid in the full amount of__________, be partially paid in the amount of__________, be totally disallowed__________.

Reasons for the above recommendations and method of calculation of recommended payment are____________

Additional comments or information:____________

Show the amount by species of) Species ____________ Amount________
the total recommended claim) Species ____________ Amount________
payment:) Species ____________ Amount________

Signed:____________ Date:____________
District Supervisor

Signed:____________ Date:____________
Damage Control Warden

Signed:____________ Date:____________
Game Warden

He then notifies the investigating officer who submits all details of what has taken place along with a recommendation for payment in full, partial payment, or no payment along with reasons for that decision. (Figure A-2).

DAMAGE CLAIM INVESTIGATION REPORT - WYOMING GAME AND FISH DEPT.

Name of Claimant ______________________ Claim Amount ____________

Species ______________ Hunt Area # __________ Management Unit # ____________

Species ______________ Hunt Area # __________ Management Unit # ____________

First notified of game damage by ______________________ on ____________ 19____.

Notification was made by letter ___, phone ___, personal contact ___, by ______________.

to Wyoming Game and Fish Department representative ______________________.

First information stated that damage was being done to ______________________

____

by ______________ and commenced ______________________ 19________.

Notification was ___ was not ___, within 15 days after damage discovery as required by W.S. 23-1-901.

The verified affidavit was received on ______________ 19______. This is ___, is not ___ within sixty (60) days after the damage or last item of damage as required by W.S. 23-1-901.

First investigation of alleged damage occurred on ______________ 19__________

by ______________ and the following condition of damage was observed.

____

____

____

Action taken: ____

____

List by date each subsequent investigation, giving findings, action taken and name of investigator: ____

____

____ (use reverse side for further comment)

That said damage was reported to the following Game Warden, Damage Control Warden, Supervisor or member of the Wyoming Game and Fish Commission, on the following date or dates, to-wit (Here specify date and person said damage was reported to)·

____

____

That hunting of the species for which the claim is filed was/was not (circle one) permitted on the above described property during the authorized hunting season.

That an access fee was/was not (circle one) charged for hunting during seasons on the above described property for the privilege of hunting the species for which the damage claim is filed.

That the total amount of access fee charged per hunter was $ ______________

(If varied access fees are charged, explain below:)

____

____

____

That I allowed the following number of persons to hunt on the above described property during the last hunting season for the species for which the claim is filed.

______________.

That the matters stated herein are true.

CLAIMANT: ______________________

STATE OF ______________)
) ss
COUNTY OF ______________)

The foregoing instrument was acknowledged before me by ______________________

this ____ ____________ day of ______________, 19__________

Witness my hand and official seal.

____
Notary Public

My Commission expires ______________________

Date Received:

____

By ______________________
State of Wyoming
Game and Fish Department

The Chief Game Warden then makes a decision on how to proceed and notifies the claimant as to that decision. If the Claimant doesn't like that decision he can appeal it before the Game and Fish Commission. If he still isn't satisfied he can take the matter before a arbitration board then on to District Court and all the way up to the Supreme Court.

As you can tell from this brief report, Wyoming has some unanswered questions regarding our Trophy Game Animal species. We need to know what the makeups are for the populations and their sizes. Some work has been done by the Inter-agency Grizzly Bear Management Team, University of Wyoming Co-op Unit and the Department to determine territories and ranges, migration routes, food sources, behavioral activities, habitat uses, and etc., but there are still a lot of unanswered questions. Also the language in the damage statute (Wyo. State Statute 23-1-901) needs to be improved to better define types of damage and allow for interpretation of statutory criteria. Without doing these things the Game and Fish Department can't really effectively regulate or manage Trophy Game Animals and can't really be effective in designing methods to control the damage keeping the resource in mind.

FIGURE A-3

WYOMING GAME AND FISH COMMISSION
CHAPTER XXVIII
REGULATION GOVERNING BIG OR TROPHY GAME
ANIMALS OR GAME BIRD DAMAGE CLAIMS

Section 1. Authority. This regulation is promulgate by authority of W.S. 23-1-302.

Section 2. Regulations and Effective Date. The Wyoming Game and Fish Commission hereby adopts the following regulation governing damage claims, filed in accordance with W.S. 23-1-901.

Section 3. Definitions. For the purpose of this regulation, definitions will be as set forth in Title 23, Wyoming Statutes, and the Commission also adopts the following definitions:

(a) "Office of the Department" means Wyoming Game and Fish Department, 5400 Bishop Blvd., Cheyenne, Wyoming 82002.
(b) "Office of the Commission" means Wyoming Game and Fish Commission, 5400 Bishop Blvd., Cheyenne, Wyoming 82002.
(c) "Damage" as used in W.S. 23-1-901 means actual damage as proved to have occurred by the claimant, to livestock, land, crops, improvements and extraordinary grass damage, and shall not include any amount for punitive damages under any circumstances.

(d) "Extraordinary Damage to Grass" as used in W.S. 23-1-901(c) means the consumption or use of noncultivated grass plants in excess of the consumption or use which normally occurred during the two years immediately preceding the time period covered by the damage claim.
(e) "Permitted Hunting" as used in W.S. 23-1-901(c) means the claimant operated in such a manner as to allow or provide for hunting on his land and access to adjoining land to allow for a harvest sufficient to meet the objectives for the area and herd.
(f) "Disinterested Arbitrator" shall mean any person, otherwise qualified, who is capable of making a reasoned and unbiased decision on evidence presented by both parties to the Arbitration Board.
(g) "Hearing" as used in W.S. 23-1-901(e) shall mean a procedually correct arbitration hearing which shall be conducted in such a manner as to afford both parties to present, examine and cross examine all witnesses and other forms of evidence received by the arbitrators. The decision of the arbitrators shall become a part of the agency file and shall be considered coevidence in the event of an appeal of the arbitrators' decision and Department file shall constitute the agency record of decision and any appeal therefrom to district court shall be conducted in conformity with the Wyoming Administrative Procedure Act.
(h) "Investigated by the Department" as used in W.S. 23-1-901(c) means a reasonable inspection of the damaged premises, crops or livestock as deemed adequate by the Department to evaluate and to report to the Commission the extent of damage incurred. Failure of the claimant to allow such reasonable inspection, upon request, shall constitute a bar to making claim as specified under W.S. 23-1-901(c).
(i) "Reasonable Service Charges" as used in W.S. 23-1-901(f) means fifty dollars ($50.00 per day while performing duties as an arbitrator.
(j) "Reasonable Expense Charges" as used in W.S. 23-1-901(f) means actual expenses incurred by the arbitrators for telephone calls, paper supplies, mail service, meeting rooms, plus per diem allowance and transportation expenses as allowed state employees by Wyoming Statutes.

Section 4. Verified Claim Requirements. The verified claim required by W.S. 23-1-901(b) shall be submitted on the form prescribed by the Department designated as "Damage Claim Affidavit". The claim shall set forth a legal description of damaged land, a description of the property damaged, the dates during which damage occurred, the type and number of big or trophy game animals or game birds which caused the damage, when the damage was delivered, to whom the damage was reported and the manner and date reported, whether or not the claimant permitted hunting during the most recent authorized hunting season for the species causing damages. Additional supporting information may be submitted and will be considered as part of the verified claim. Amended damage claims may be filed with the office of the Department in the event that all information is not immediately known by the claimant. In any event, the entire claim must be submitted in writing to the office of the Department within 60 days of the last item of damage.

Section 5. Arbitration Notification Procedure. During the process of establishing an arbitration board to act upon a damage claim, written notification will be made from the claimant to the office of the Department and from the Department to the claimant regarding the names and mailing addresses of arbitrators selected by them. The two arbitrators selected shall notify in writing both the claimant and the office of the Department of the name and address of the third arbitrator selected.

Section 6. Savings Clause. If any provision of this rule or its application to any person or circumstance is held invalid or in conflict with any other provisions of this rule, the invalidity shall not affect other provisions or application of this rule which can be given effect without the invalid provision or applications and to this end the provisions of this rule are severable.

Wyoming Game and Fish Commission

by
Dennis Daly, President

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Coyote Control in Alberta[1]

John B. Bourne[2]

Abstract.--A historical review of coyote damage to livestock, early control measures and the development of Alberta's coyote damage control program is provided, including provincial and federal legislation, provincial policy, research and field testing initiatives, extension and control methodology.

INTRODUCTION

I would like to outline Alberta's coyote damage control program by chronicling its development from early times to the present.

HISTORY OF COYOTE CONTROL

Predator damage control in Alberta and specifically coyote control, had its earliest beginnings when European immigrants settled this province less than 100 years ago. Prior to that, Hudson Bay Company's records document profitable and sizeable catches of "prairie wolf" until the time of settlement on the Canadian prairies (Newman 1985).

Bounty System

Prairie homesteaders describe protecting poultry and young livestock from coyotes by leghold traps, coyote poison, horse and hound chasing. Prior to and during World War I, homesteaders and local governments unified their resources and funds to support a bounty on coyotes. Local municipal records in 1921, for instance, show 6500 pairs of coyote ears turned in for the $2.00 bounty paid in south central Alberta. The bounty system (fig. 1) for coyotes flourished almost continuously until withdrawal in 1948 (Todd and Geisbrecht 1979).

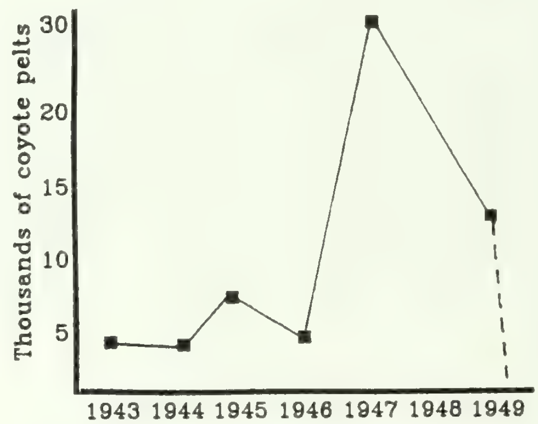

Figure 1. COYOTE BOUNTY 1943-1948

Division of Responsibility

In 1941 game law enforcement and regulatory services of Alberta Agriculture were transferred to the Department of Lands and Forests. Thereafter, fish and wildlife management and game enforcement were the mandate of the Lands and Forest for all species, except those recognized as agricultural pests such as the black-billed magpie, Norway rat, coyote and field rodents. Alberta Agriculture continued to control the coyote in agricultural areas. Control of sport hunting and trapping coyotes, province wide, was and is, the responsibility of Fish and Wildlife (Annual Report 1946).

Early Legislation

In 1948, the unregulated and indiscriminate use of snares, traps and poisons on private land ended with the introduction of legislation that regulated the use and distribution of poisons for coyote control. The Agricultural Pests Act identified persons who could use or issue poisons. In the same year, coyote getters and 1080 poison were acquired by Alberta Agriculture from the USBSFW and used for coyote control. Prior to 1948, strychnine was the primary poison for coyote control.

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. (Colorado State University, Ft. Collins, April 19-20, 1989).

[2]John B. Bourne is Regional Supervisor Problem Wildlife, Government of Alberta, Vermilion, AB.

RABIES EPIZOOTIC

In the early 1950's, positive diagnoses of rabies was confirmed in red foxes in northern Alberta when fox populations were at their apex. In 1952, rabies was enzootic in red fox in northern Alberta and the disease was very quickly transmitted to other carnivora including coyotes, wolves, bears and lynx. An intensive vector control program was soon underway; the major control agents and animal removal methodology was fashioned after the coyote damage control program. Over 2 million strychnine baits were used for rabies control during 1952-1956. When the campaign terminated nearly four years later, records indicate 150-170 thousand coyotes and 10-15 thousand wolves were destroyed (Ballantyne 1958).

COUNTY COYOTE CONTROL PROGRAM

At this time, Alberta Agriculture and rural counties were entering a new age of post war agricultural production, advanced agronomy, harvest-mechanization production and changes in land use practices. To deal with the agriculture issues, rural counties hired and trained agricultural fieldmen to conduct cooperative programs and enforce legislation and policy. All county agriculture programs were cost shared 60:40 with Alberta Agriculture. Included in the government and county agreement, was the county responsibility of coyote control (Annual Report 1953).

Alberta Agriculture established procedures and standards of conduct for coyote control, trained county fieldmen and supplied poisons and materials for coyote control. In 1953, Alberta Agriculture began purchasing from the USBSFW its third toxicant, 140 mg strychnine tablets.

Partly as a result in changes in agricultural management practices and new developments in the livestock industry, cattle numbers increased rapidly while sheep and lamb numbers declined. In 1940, there were 1.36 million cattle and .88 million sheep. By 1960 these numbers changed to 2.7 million cattle and .55 million sheep and by 1980 3.73 million cattle and .2 million sheep.

LIVESTOCK PRODUCTION

In the 1970's, livestock production and particularly cattle production, in Alberta increased steadily and continuously. This was due in part to government incentives, low cost breeding animals and availability of low cost marginal land. Also, production of other livestock and poultry increased substantially but for slightly different reasons. As expected, predator complaints and reported losses paralleled industry growth (Annual Report 1970). Also, wolf predation on livestock was reported in the 1970's, something almost unheard of since wolf populations were believed to be still recovering from the rabies depopulation campaign twenty years earlier.

NEW PROGRAM

To reduce off producer complaints, Alberta Agriculture hired ten predator specialists in 1972. Fish and Wildlife also hired or transferred staff to deal with carnivore predation in the forested areas. (Alberta Energy & Natural Resources 1976). Alberta Agriculture predator specialists provided additional assistance to county fieldmen to aid in resolving coyote predation. Until 1972, most coyote control was conducted by county personnel.

Compensation

In 1974 Alberta Agriculture implemented a compensation program to indemnify producers for livestock and poultry losses attributed to predation. Owners of confirmed predator killed animals were recompensed at 80% market value at time of damage. Annually some 500-1000 complainants receive about two $250,000 for coyote losses. Confirmed poultry losses account for about 10% of the total monies paid out (Annual Report 1987).

Federal-Provincial Legislation

Authority to use predacides is under both federal and provincial laws. The Agricultural Pests Act establishes who may issue and set out poisons, while the federal Pest Control Products Act specifies toxicant storage, disposition, toxicological data, worker safety, first aid and specific uses. Prior to 1984 provincial governments could use predacides without federal registration.

Coyote Control Techniques

Lethal neck snares were permitted as a control device was completed in 1984. Lethal neck snares are not classified as restrictive, therefore, do not require federal registration. Also in 1984 140 mg strychnine, 760 mg sodium cyanide, 5 mg 1080 tablet, 5 mg liquid 1080 and 600 mg liquid 1080 were registered with the federal government. Other techniques used in coyote control include leghold traps, guard dogs, electric fences, den hunting and shooting. Aerial shooting is not allowed in Alberta.

PROGRAM OPERATIONS

During the last five years the focus of Alberta's coyote damage control program has shifted from direct assistance to producer training and extension. Part of this change was due to fiscal restraint. Other factors include increased government demand for safer use, care and welfare for the user of restricted devices. This has resulted in a reduction in provincial predator specialists, more work done by counties, greater restriction on use of poisons and fewer toxicants used. To counter this, greater extension efforts have resulted in promotion of preventive techniques and general producer education.

Long term program objectives include promotion of preventative and non lethal control measures. Attaining these goals is made easier by the new era livestock producer, particularly the sheep farmer who is younger, better educated, more experienced and a little more affluent than the previous generation. This results in many innovative and creative producers willing to risk new off-farm ideas.

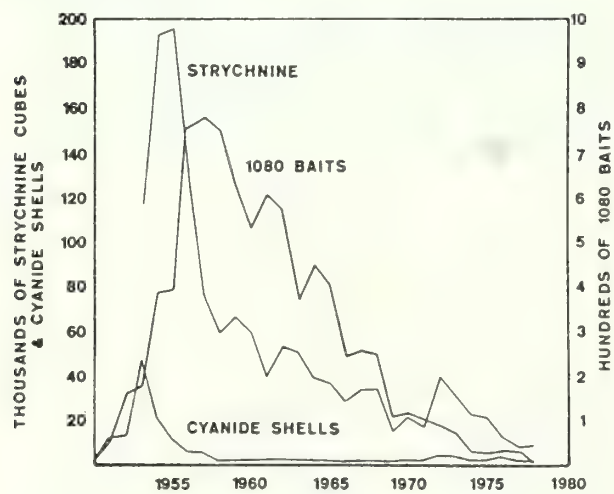
In training producers, the primary consideration in establishing a predation free operation is appropriate and adequate animal husbandry. Many coyote-sheep conflicts occur as a result of poor or unsuitable livestock management practices. Predation would decline if producers constructed sound barrier fences, properly disposed of livestock remains and followed closer herding regimes of their flocks.

Since our initial field test ten years ago, electric fences (Dorrance and Bourne 1980) are now the primary control agent on nearly 25% of all major sheep operations. The rapid growth of electrical technology in fence energizers and other equipment and materials, along with new designs and configurations, have made electric fences very attractive to sheep producers.

Other proven preventative measures are guard animals (including dogs), special herding regimes, routine den removal and a continuum of home variations and remedies of the above.

This has resulted in a significant decrease in and more efficacious use of toxicants (fig. 2). Since 1984 overall toxicant use has decreased and toxicant choice has shifted from strychnine to 1080 (table 1).

Single dose 1080 tablets and liquid 1080 has all but replaced strychnine and the large winter 1080 meat baits.



TOXICANTS FOR COYOTE CONTROL

Figure 2.--(illustrates total toxicant use in Alberta since regulatory authorization began in 1953)

Table 1. TOXICANTS DISTRIBUTED FOR COYOTE CONTROL

Year	Cyanide Shells	Strychnine Cubes	Single Dose 1080	Large 1080 Baits
1978	1549	6670	-	0
1979	1453	6100	-	14
1980	1041	3840	-	14
1981	1672	3700	-	13
1982	1642	3700	-	13
1983	1278	3593	-	16
1984	1175	4184	147	15
1985	873	2609	346	16
1986	482	2166	558	8
1987	565	1567	1769	8

Today, predator specialists spend four and one-half man years investigating about 500 coyote complaints in 65 counties (table 2). Generally predator specialists, working with producers and in many cases with county fieldmen, spend about 20 hours resolving each coyote predation complaint. This is about double the time spent 15 years ago, however, the number of return visits is less than 50%. Predator specialists and county fieldman provide direct control assistance to about 75% of the reported coyote predator claims for compensation (Rodtka, 1989). About 25% of coyote complaints are handled independently by the producer.

Alberta Agriculture produces a number of multimedia articles, slide tape productions and hands-on training workshops for producers to enhance awareness of and need for sound principles of coyote predation control.

Table 2. NUMBER OF CASES AND TOXICANTS SET

Year	Number of Cases	Number of Toxicants Issued	Number of Toxicants Per Case
1984	520	4125	7.9
1985	528	2933	5.6
1986	398	1945	4.9
1987	513	2530	4.9

CONCLUSION

Given the support, cooperation and assistance shown by producers, municipalities, the general public and other agencies such as Fish and Wildlife, Alberta's coyote damage control program appears secure and in tact. I regret that I can not provide an inspired personal vision for the future. Like others, I can only gaze into that

munificent crystal ball. Unfortunately this will not help, for as our former minister once lamented, one can not look into a crystal ball unless one is able to eat ground glass.

No doubt there will be further challenges of budget expenditures and fiscal policy, but with strong leadership, political will and continued support, coyote damage control will prevail in Alberta. There will probably be:

1. Reduced use of poisons and more restrictions on their use.

2. Greater emphasis on non-lethal preventative techniques, particularly electric fences which work very effectively on most operations in Alberta.

3. Greater concern for humane methods of control.

4. More pressure from environmental groups and other organizations concerned with animal rights and humane treatment of wild and domesticated animals.

Alberta Agriculture attempts to make changes in coyote control policy and programs before there is public pressure to do so. It attempts to strike a balance between the real and perceived needs of the farmer and the concerns of environmental and animal welfare groups.

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Texas Department of Agriculture Predator Management Program[1]

Murray T. Walton[2]

Abstract.--In 1988, the Texas Department of Agriculture initiated predator management training and certification for sodium monofluoroacetate (Compound 1080) Livestock Protection Collar applicators and recertification of M-44 sodium cyanide applicators. Training included alternative methods and promoting livestock guard animals. Fifty-four training sessions had an attendance of 879 persons. M-44 applicators were reduced from approximately 5000 to fewer than 700. One hundred twenty-eight individuals obtained Livestock Protection Collar licenses and 43 purchased collars. Results of collar use and measures to increase effectiveness of training and application are discussed.

INTRODUCTION

Texas ranks first in the nation in production of cattle, sheep, and goats and in the top 10 in poultry production (Texas Agricultural Statistics Service 1986). Unfortunately, predators take about 1% of the annual calf crop (Stalcup 1988) and approximately 190,000 sheep and goats each year (Mulder 1988).

Lesser but significant numbers of poultry and adult sheep and goats are also lost to predators. Annual losses are valued at approximately $30 million. Coyotes account for a majority of the damage (Clay 1987). Other predators of primary concern are eagles, bobcats, gray and red foxes, dogs, and feral hogs.

As the state agency with regulatory responsibility for pesticides, the Texas Department of Agriculture (TDA) administers a certification and training program for use of the 2 poisons, M-44 sodium cyanide and sodium fluoroacetate (Compound 1080) Livestock Protection Collars (LPC), registered for predator control in Texas.

TDA seeks to achieve a balance between the valid concerns over livestock losses and the equally valid need to protect wildlife and the environment. Due to the hazards of pesticide use and the limited applicability of M-44s and Livestock Protection Collars, TDA encourages the use of non-lethal methods of predation management where possible. In particular, TDA promotes the use of "Texas bred" livestock guard animals.

The M-44 is a patented spring-operated device used with a toxicant (Shult 1976). Its use in Texas with sodium cyanide capsules is registered as a state-limited-use pesticide for use in controlling coyotes, foxes, and feral dogs preying on livestock and poultry. The method of operation and bait used the with M-44 make the device highly selective for canids.

The Livestock Protection Collar is a rubber bladder containing a toxicant with straps for attachment to the neck of sheep or goats (Rancher's Supply Inc. N.D.). LPCs containing Compound 1080 are registered as a state-limited-use pesticide for taking coyotes attacking sheep and goats by bites to the throat. Only the small collar for use on animals from 15 to 50 pounds is registered for use in Texas. The LPC is the most specific device developed for taking offending animals.

TRAINING AND CERTIFICATION

TDA has conducted a program since 1977 for training and certification of M-44 sodium cyanide applicators. The turmoil over

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Fort Collins, Colorado, April 17-20, 1989].

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registration of the LPC caused TDA to re-evaluate its program and work with the Texas Agricultural Extension Service, Texas Animal Damage Control Service, National Audubon Society, Lone Star Chapter of the Sierra Club, Animal Rights Kinship, Inc., the Humane Society of the United States, the Texas Farm Bureau, and the Texas Sheep and Goat Raisers Association to develop a comprehensive predator management approach. Especially helpful to the effort were State Senator Bill Sims, Executive Secretary of the Texas Sheep and Goat Raisers Association, and State Representative Dudley Harrison, Chairman of the Texas House Agriculture and Livestock Committee. This comprehensive approach was key to collar registration for use in Texas and has avoided public controversy.

TDA's training program leading to certification of M-44 and LPC applicators includes instructions on identification of predation, legal alternative methods of predator control both non-lethal and lethal, as well as proper use, safe handling, emergency first aid, recordkeeping, and reporting requirements for M-44 and LPC applicators as required by pesticide label use restrictions. Lecture, slide/tape, and demonstration are used as teaching methods. All participants are provided a manual developed by TDA for M-44 only training or M-44 and LPC training. Manuals contain an outline of all materials covered during training sessions including pesticide label(s), reporting forms, and first aid treatment. The training program relies heavily on material developed by the Texas Agricultural Extension Service for identification of predation and use of collars.[3,4] Seven TDA staff members are trained and equipped to conduct the sessions.

Requirements for M-44 certification include attendance at a training session (2 1/2 - 3 hours) and possession of a private applicator license or certified applicator license for purchase and use of state-limited-use or restricted-use pesticides. Training, M-44 certification, and private applicator license were available with no fee.

In order to obtain a non-commercial certified applicator license to use the Compound 1080 Livestock Protection Collar, a person must complete the training (approximately 6 hours), score 70 or above on the prescribed test and obtain a license. A $20 testing fee must be collected before a person may take the test (2 opportunities to pass the test are allowed without retraining). The annual license fee is $50 for a non-commercial LPC applicator's license. State and federal agency personnel acquiring a non-commercial license to perform official duties are exempt from fees. For a commercial LPC applicator license, a person must complete the training, pass the test, provide proof of financial responsibility and pay an annual license fee of $150.

During 1988, the Texas Agricultural Extension Service assisted TDA in holding 54 predator management training sessions, and TDA conducted an additional 5 sessions for small groups. Twenty-eight of the sessions included LPC training. The first 11 LPC training sessions in the Spring of 1988 were scheduled within weeks of approval of the TDA certification program by the U. S. Environmental Protection Agency in April 1988. Training was made available within a 2-hour driving distance of 90% of the sheep and goats in Texas to provide an opportunity for producers to use collars in 1988.

During the summer of 1988, all certified M-44 applicators were mailed a notice of recertification requirements and provided a reply card for requesting a schedule of training sessions. A more extensive state-wide schedule of training was then held in the Fall of 1988 to recertify M-44 applicators as required by Texas pesticide regulations.

Total attendance at the 59 predator management training sessions was 879 persons with 829 receiving credit for M-44 training and 280 receiving credit for LPC training. Fewer than 700 subsequently satisfied all requirements for M-44 certification. Of those completing LPC training, 194 took the LPC examination with only 4 failures. One person failing the examination subsequently retested and passed. One hundred twenty-eight of those passing the exam acquired licenses.

Due to the start of LPC training well after Spring lambing and kidding, the attendance and resulting number of licensed LPC applicators was considered excellent. The 700 M-44 applicators represents a considerable reduction from the nearly 5,000 certified applicators on record prior to the November 1, 1988 date required for recertification to continue use. However, this drop in applicator numbers is not surprising. Only 100 to 150 applicators purchased M-44 Sodium Cyanide capsules in 1986, 1987, or 1988. Furthermore, a survey of Texas sheep and goat producers conducted in 1978 found that only 14% used the M-44 and rated it the least effective of all control methods reported (Texas Crop and Livestock Reporting Service 1979).

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[3] Wade, Dale A. and James E. Bowns, 1985. Procedures for evaluating predation on livestock and wildlife. Texas Agricultural Extension Service, B-1429, 42p.

[4] Wade, Dale A., 1985. Applicator manual for Compound 1080 in Livestock Protection Collars. Texas Agricultural Experiment Station, B-1509, 50p.

All participants at training sessions are provided an evaluation form to rate the program and offer suggestions. A vast majority have rated it good to excellent.

LIVESTOCK GUARDING ANIMALS

Many Texas sheep and goat raisers are successfully using livestock guarding animals, particularly donkeys and guarding breeds of dogs. A number of Texans are now raising livestock guarding animals. TDA promotes the marketing of livestock guarding animals as a cost effective and socially acceptable alternative to poisons and other lethal control methods. The Department maintains a list of Texas Livestock Guarding Animal Breeders. Prospective purchasers of livestock guarding animals may obtain a copy of the list by contacting the Department. This list is also included in the Department's predator management training manuals for M-44 and LPC applicators.

Promotional activities in 1988 included a press conference on the State Capitol grounds featuring Texas Agriculture Commissioner Jim Hightower along with 3 guarding dog breeds, a donkey, a llama, and their owners present for testimonials. This event in January 1988 received statewide and national press coverage. Further media coverage was afforded through three television appearances, and production of a short television news story featuring a goat raiser/great pyrenees producer, and several radio interviews.

The reply card sent to 4,700 M-44 applicators about recertification also had boxes to check for those wanting to attend LPC training, to attend a livestock guard animal field day, or to receive a guard animal producer list. Eighty-seven wanted LPC training, 121 responded that they wanted to attend a guard animal field day, and 79 requested the guard animal producer list. Other program requirements have resulted in the field day remaining in the planning stages.

1988 LIVESTOCK PROTECTION COLLAR-USE

During 1988, 43 licensed Livestock Protection Collar applicators purchased a total of 827 collars. Counties with applicators possessing collars are shown on Figure 1. Nine applicators with 20 collars each (180 total collars) kept collars in storage in 1988 and reported no use. The remaining 34 applicators used 524 of the 647 collars in their possession.

Of the 524 collars actually used by applicators, 30 were reported as punctured by coyotes, 39 were reported as missing/lost as of December 31, 1988, 15 were pierced or torn by vegetation, 4 were ruptured from unknown causes and 1 was torn during removal. The only reported instance of suspected non-target Compound 1080 induced mortality involved a lamb with a collar ruptured from an unknown cause. Other verified mortality (excluding kills with collar punctures and collared animals lost) involving collared animals included 4 livestock deaths from unknown causes, 1 collared animal killed by a predator without the collar being punctured, 1 collared animal broke a leg while caught in a leg-held trap and was destroyed, and 1 animal was destroyed after being contaminated by Compound 1080 from a collar ruptured during removal.

Minimum, maximum and average Livestock Protection Collar use-days were calculated from "Livestock Protection Collar Quarterly Applicator Data Report" forms submitted by applicators. Minimum collar use-days were determined by adding the number of days from attachment to the last collar inspection on which collars were found to be in good condition. Maximum use-days were determined by adding the intervening period between the last date on which collars were in good condition until the date on which collars were detected to be lost, punctured, torn, or rendered unsuable. An average estimate of 25,694 collar use-days for 1988 was calculated from the maximum and minimum use-days.

Eighteen licensed collar applicators suspected taking from 1 to 5 coyotes with a total estimate of 37 coyotes taken with collars. This estimate was based on collar punctures which resembled coyote tooth marks, finding dead coyotes with dye stained teeth, missing collared livestock, cessation of predation, and other factors. At a minimum, 7 dead coyotes suspected to have been killed by collars were found. Two of the coyotes found dead were suspected to have been killed from puncture of a single collar.

Considerable variation was recorded among applicators in collar use-days required to take coyotes. Results were achieved in 1 night to several months with 4 to 48 collars in use. The lowest average number of use-days per puncture suspected of taking a coyote recorded by an applicator for 1988 was 35 use-days. This applicator placed only 8 collars on goats, recorded 5 punctures and found 2 dead coyotes in less than one month's time. Overall use-days per suspected coyote kill averaged 697 use-days.

These results compare very favorably with tests performed by the Texas Agricultural Experiment Station (1983) from August 1980 through April 1983. Data was collected for 55,735 collar days on an "intensive" site and 35,552 collar days on a "rancher-use" site with 67 and 26 collars, respectively, known to be punctured by predator attacks. This translates to 832 use days and 1,367 use-days per suspected coyote kill. The Texas Agricultural Experiment Station study recorded a number of attacks (63) where collars were not punctured. TDA only had 1 non-puncture attack on a collared animal reported, however, 39 animals were reported as missing or lost. In 1 instance of a missing

FIGURE 1.--Distribution of applicators purchasing Livestock Protection Collars in 1988

collared animal, a LPC applicator reported to TDA that a dead coyote was located.

Also, the reports of 7 dead coyotes found by Texas LPC applicators in 1988 compares extremely well with recoveries of 3 dead coyotes from 30 collar punctures reported by Connolly (1980).

Inspections of 30 applicators were performed in Calendar Year 1988. Only 1 significant infraction of Livestock Protection Collar use restrictions and TDA regulations has been detected to date. This incident involved use by a non-certified applicator who was provided collars by a licensed applicator. The primary problem encountered was slow reporting of collar use.

LIVESTOCK PROTECTION COLLAR PURCHASERS

Licensed LPC applicators purchasing collars in 1988 represent a good cross section of the Texas sheep and goat industry. They included producers that had entered the business for the first time in 1988 and representatives of families with generations of experience. More than half of the collar users raised both sheep and angora goats. Herd size varied from

slightly less than 200 animals to about 3,300 head, and acreage used for sheep and/or goat production ranged from about 200 acres to 18,000 acres. Predation losses reported to TDA ranged from a couple of animals per year to 450 head. One producer reported loss of 273 lambs out of a 1988 crop of 280 lambs. Collectively, applicators purchasing collars reported losses of approximately 3,000 sheep and 1,800 goats in the previous two years. They had slightly in excess of 29,000 sheep and 22,000 goats on hand at the time collars were acquired.

Thirty-four returns of a questionnaire sent in December 1988 to 42 applicators with collars showed 27 LPC applicators claiming increased predation in 1988, 4 with predation stable, 2 with a decrease in predation, and 1 new producer without prior experience. All indicated predation on sheep and/or goats by coyotes. Second in frequency was predation by dogs. Other predators of major concern were fox, bobcat and eagle. All respondents to the questionnaire used a variety of predator management methods other than collars. Twenty of the replies indicated that assistance was received from the Texas Animal Damage Control; 13 reported using donkeys as guard animals; and 8 reported using livestock guard dogs.

In response to a question on the adequacy of TDA's training program, 33 of 34 responses indicated it was adequate for effective use of collars. The 1 negative response cited inadequate training in "bookkeeping". In a follow up question on what areas of training should receive more attention, 8 indicated targeting/livestock management, 5 checked completing forms, and 2 marked safety. The latter is surprising as safety is stressed throughout training.

The training program is admittedly light in regard to targeting. Collar users were directed to contact Mr. Roy McBride of Rancher's Supply, the collar manufacturer and registrant for Texas, for additional advice on targeting. Recommendations on targeting are also provided on an individual basis by TDA Predator Management Specialists during annual inspections. However, it appears difficult to convince some applicators to use enough collars.

Though instructions for completing forms appear to be a simple matter, it is an area of major difficulty for producers not accustomed to paperwork. To remedy the problems with reporting forms, more attention is being given during training and inspections, completed sample forms are being added to manuals and sent to collar users, and changes have been made in the quarterly report form.

SUMMARY/CONCLUSIONS

A comprehensive approach to predator management training that includes non-lethal as well as lethal means engenders less public controversy and better meets the needs of livestock producers because no one method of predator management suites all situations. TDA's predator management program for training and certification of M-44 sodium cyanide applicators and sodium monofluoroacetate (Compound 1080) Livestock Protection Collar applicators along with the promotion of livestock guarding animals attempts to strike a balance between producers concerns over livestock losses and equally valid needs to protect the environment. Reception of the training program by livestock producers has been excellent with more than 800 attending training sessions in 1988. The training program needs improvement in the areas of targeting collar use and completion of reporting forms.

There is a growing interest in the use of livestock guarding animals and training in their use is needed. Use of M-44 sodium cyanide by individual livestock producers remains limited. Few Texas sheep and goat producers (34) availed themselves of the opportunity to use Livestock Protection Collars in 1988. Several producers were highly successful in taking coyotes responsible for thousands of dollars of damage to livestock. Use of collars supplemented other means of predator control and proved effective in some instances where all other efforts failed and continued use is warranted. Efficiency could be improved by using collars only where and when incidence of attack to the throat of sheep and/or goats is high, rather than in a prophylactic manner as practiced by several applicators. Failure of several collar applicators to take coyotes during prolonged periods of predation can probably be attributed to an inadequate number of collared target animals in pastures with greater numbers of uncollared animals of the same size and species. However, targeting was successful even with the use of a small number of collared animals (4 to 8) when small lambs or kids were placed with a larger number of adult animals.

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The Texas Department of Agriculture gratefully acknowledges the assistance of the Texas Agricultural Extension Service in conducting predator management training sessions in 1988.

APHIS Animal Damage Control Livestock Guarding Dog Program[1]

Jeffery S. Green[2]

Abstract.--One hundred traditional breed livestock guarding dog pups were placed with sheep producers in Wyoming, Idaho, Oregon, and Washington during 1987-88 as part of the APHIS Animal Damage Control program. Producers reared the dogs and integrated them into their operations. Ninety-three dogs were rated as follows: 68% good, 17% fair, and 15% poor. Success was breed-related. Sixty-one percent of the dogs were used on pasture operations and 39% on range operations. Nineteen percent of the dogs died prior to reaching 18 months-of-age.

INTRODUCTION

Included in the transfer of the Animal Damage Control (ADC) program from the U.S. Department of the Interior, Fish and Wildlife Service to the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service in December 1985, was the responsibility for funding and oversight of a guarding dog pilot program in Oregon and Minnesota. Briefly, the objective of the Oregon program was to promote the use of livestock guarding dogs as a method of reducing coyote depredation on sheep. The focus in Minnesota was wolf depredation.

A Congressional Directive in fiscal year 1987 (FY-87) expanded the pilot program in the west to include Washington, Idaho, and Wyoming. An unspecified amount of funds were to be used to purchase guard dogs for placement with livestock producers.

To fulfill the directive, ADC established cooperative agreements with Oregon State University Extension Service (OSES) and USDA's Agricultural Research Service (ARS) to use their guarding dog specialists to conduct the programs in the 4 western states.

In FY-88 Congress renewed their directive to ADC to administer the dog program and continue the purchase and placement of dogs. To more adequately fulfill the directive, ADC discontinued the cooperative agreements with OSES and ARS and employed a guarding dog specialist in February 1988 to conduct the western program. The program in Minnesota was conducted by other ADC Specialists.

For FY-89, the directive was reissued to ADC with several modifications. Montana was to be included in the western program, and Federal funds were not to be used in the direct purchase of dogs. Efforts were to focus on information dissemination and education. ADC employed a second dog specialist in November 1988 to assist conducting the western program.

This paper focuses on the dogs that were purchased with Federal funds and placed with livestock producers in Wyoming, Idaho, Oregon, and Washington during 1987 and 1988.

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[1]Paper presented at the Ninth Great Plains Wildlife Animal Damage Control Workshop [Colorado State University, Fort Collins, April 17-20, 1989].

[2]Jeffrey S. Green is Wildlife Biologist, Livestock Guarding Dog Specialist, USDA-APHIS, Animal Damage Control program, U.S. Sheep Experiment Station, Dubois, ID 83423.

METHODS

Dogs were purchased from commercial breeders who could supply registered pups of recognized livestock guarding breeds with parental stock free from hip dysplasia. In general, pups could be no older than 8 weeks-of-age if not reared with sheep or goats or 12 weeks-of-age if they were reared with sheep or goats.

Most pups were brought to the U.S. Sheep Experiment Station near Dubois, Idaho for early socialization to sheep until they were placed with producers. Some pups were delivered directly from the dog breeder to the sheep producer.

Sheep producers were selected for participation in the program based on several criteria: the magnitude of their predator problem or potential for predation, whether they were a commercial producer with a minimum of 25 ewes and/or nannies in either pasture or rangeland operations, and their enthusiasm and willingness to participate in the program. Priority was given to producers with no guarding dogs and with an ongoing predator problem. Finally, dogs were distributed between the 4 states in consideration of the number of sheep producers and the extent to which guarding dogs were already being used in the state. The objective was to promote the use of dogs in areas and types of situations where they had not been tried previously.

Producers selected for the program were provided literature on the concepts of raising and training a guarding dog. They were counseled by a guarding dog specialist either personnally or by telephone on how to rear the pup and integrate it into their operation. Some producers viewed a slide series on the use of guarding dogs, and some operations were visited by the specialists when the pup was delivered. All producers were encouraged to contact the dog specialist if they had questions or problems working with the dog.

Dogs were rated using the following criteria: 1) the frequency of occurrence of significant problems (e.g. dog wandering excessively; dog harassing, injuring, or killing livestock; dog posing a serious threat to people; dog seriously disrupting sheep management), 2) evidence of the dog displaying guarding behaviors (e.g. barking at disturbances, moving around the sheep, remaining near the sheep), 3) the dog's apparent effect on the incidence of predation, and 4) the producer's satisfaction with the dog.

Data on the dog's performance was gathered from producers through personal visits, telephone conversations, and a written questionnaire. I assigned one of the following ratings to each dog: good - dog generally remained near sheep, incidents of predation markedly reduced or kept to a minimum, minor problems, producer pleased with results; fair - dog had potential, predation somewhat reduced or unchanged, benefits outweighed problems; or poor - dog had no influence on predation and major problems outweighing benefits. Chi-square procedures were used to analyze the data.

RESULTS AND DISCUSSION

One hundred livestock guarding dogs were purchased from summer 1987 through summer 1988. Most of the dogs were Great Pyrenees and Anatolian Shepherds (Table 1). With 1 exception, the dogs were pups, and the majority were between 7 and 8 weeks-of-age. Mean purchase price (± Standard Error) including shipping (applicable for 63 dogs) was $443 ± 7, range $250-550. Mean prices for individual breeds and other data are in Table 1.

Eighty-two sheep producers received guarding dog pups. Forty-five pups were placed in FY-87, 55 in FY-88. The number of dogs and producers, respectively, for each state are as follows: Idaho, 36 and 26; Wyoming, 35 and 29; Oregon, 16 and 14; and Washington, 13 and 13. Most producers (n = 67) received 1 dog each. Thirteen range producers received 2 pups, and 1 received 4. Three producers received a second dog following the early accidental death of their first pup.

Ninety dogs remained with the producer they were initially placed with. The remaining dogs (n = 10) were moved to other operations primarily due to the dogs' poor performance. Two producers left the sheep business necessitating moving the dog. The number of dogs in the program is not static due to deaths, and the number of producers varies for the reasons mentioned previously. The remainder of this report will primarily discuss the results of the program as they existed as of 1 January 1989. If the discussion varies from this qualification, it will be noted.

Ninety-three dogs survived long enough to be rated on their performance. Sixty-eight percent were rated good, 17% fair, and 15% poor (Table 2). Great Pyrenees were rated higher than Anatolian Shepherds ($\underline{P} < 0.01$). Sample size was insufficient to allow meaningful

statistical comparisons with the other 2 breeds.

A recent survey of almost 400 livestock producers who used dogs (n = 763) revealed no breed differences (Green and Woodruff 1988). One possible reason for the differential rating for Anatolians in the survey and this study may be age of the dogs. Dogs in the survey were generally older than those in this study, and it is likely that some of the Anatolian Shepherds in this program will ultimately become good guardians. However, particularly as young dogs, Anatolian Shepherds are clearly more problematic than Great Pyrenees.

Ratings did not differ between the 36 dogs used on rangeland and the 57 used on pastures nor between males and females ($P > 0.05$). With few exceptions, all of the dogs were neutered, females at approximately 6 months-of-age and males at approximately 9 months-of-age.

Forty percent of the dogs injured livestock, and 15% killed livestock (Table 3). More Anatolian Shepherds were involved in both activities than Great Pyrenees ($P < 0.01$). Most of these incidents occurred as the dogs were pups and did not persist as the dogs matured. Two dogs (1 Kuvasz, 1 Great Pyrenees) were culled because they were judged incorrigible in this behavior. One Anatolian was culled also, due in part to this behavior. One young Akbash Dog was with sheep in a corral that was visited by an intruding dog during the night. The sheep piled up, and 70 ewes died. Details of the incident are unknown.

Nineteen of the 100 dogs are no longer in the program (data as of March 1989). Three were culled, and 16 died or disappeared. (Hereafter, all 19 will be termed deaths). Vehicle mishaps and accidents were responsible for the majority of deaths (7), followed by disappearance (4), unknown illness and culling (3 each), and poisoning (2). Nine died between 4 and 9 months-of-age, and 10 died between 10 and 18 months-of-age.

Table 1.--Purchase data for dogs in the ADC dog program.

Breed	n	Number of breeders	Number of different breedings	Mean price ($)
Great Pyrenees	65	19	21	418
Anatolian Shepherd	27	6	8	504
Akbash Dog	5	2	2	478
Kuvasz	3	1	1	400
Total	100	28	32	443

Table 2. Ratings of performance of ADC livestock guarding dogs. (Percentages in parentheses)

Breed	Good	Fair	Poor
Great Pyrenees	49 (83)	7 (8)	3 (9)
Anatolian Shepherd	10 (38)	7 (27)	9 (35)
Akbash Dog	4 (80)	1 (20)	0
Kuvasz	0	1 (33)	2 (67)
Total	63 (68)	16 (17)	14 (15)

Table 3. Dogs that injured or killed sheep. (Percentages in parentheses)

Breed	Injured sheep	Killed sheep
Great Pyrenees	14 (24)	4 (7)
Anatolian Shepherd	19 (73)	8 (31)
Akbash Dog	1 (20)	1 (20)
Kuvasz	3 (100)	1 (33)
Total	37 (40)	14 (15)

Lorenz et al. (1986) reported a higher mortality for dogs on rangeland than pastures. No difference between range and pasture deaths was noted for dogs in this study (17% of range dogs, 23% of pasture dogs, $P > 0.05$), however, the dogs are yet comparatively young.

Of the 81 dogs currently alive, 25 (31%) are < 12 months old, 55 (68%) are between 1 and 2 years old, and 1 (1%) is > 2 years old.

At least 25 producers reported a decrease in predation which they attributed to the presence of their guarding dog. Some termed the decrease "significant" or "remarkable," and others said the dog has "helped." Data from several of these producers for annual totals of sheep lost to predators before using a dog and while using a dog, respectively, are as follows: 70 and 19, 15 and 0, 300 and 30, 490 and 66, 30 and 0, 40 and 0, 70 and 4, 25 and 0, 65 and 5, 700 and 500, 175 and 115.

There are several caveats to be considered with this type of data. Some producers are unable to keep accurate data on predation loss or may not be

inclined to do so in light of other more pressing duties involved with livestock production. Producers continued to use other methods of reducing predation including good livestock management and traditional removal techniques provided by ADC Specialists (trappers) or other professional trappers. The level of depredation is not static between years. It is therefore difficult to definitively attribute a specific level of reduced predation to one control activity. Perhaps the most important evaluative criterion is the producer's general assessment of the value of a control tool.

Several producers noted a reduction in predation and attributed it to the dog, but behavior problems with the dog precluded using the dog further. At least 10 producers are hopeful that the dog will be effective but have not yet seen a reduction in predation.

Several dogs were caught in coyote traps, but none have died as a result of legal predator control activities. At least 2 dogs were poisoned, but the source of the poisoning was not reported. One dog was observed to kill a coyote.

On some operations, while performing their control activities, ADC Specialists made observations on the dogs' performance. In general, these observations confirmed the reports provided by the producers. At least in some instances, there were too many coyotes for a young guarding dog to keep predation minimized. A combination of trapping and other effective removal techniques along with a dog appeared to be essential in keeping losses to predators low. This further illustrates what knowledgeable people have continually advocated, that to achieve success in reducing predation, a variety of control techniques is necessary.

Because the dogs are relatively young, another year's data on predation losses will be important to adequately evaluate the dogs' effectiveness.

Despite various problems with some of the dogs, most producers are pleased with the results to date and in many instances attribute at least some of the reduction in predation to the dog. No fewer than 1 dozen producers have or intend to purchase additional guarding dogs to use in their operations. One range producer in Wyoming commented that if his guarding dog ever learned to write checks and pull camps, he'd have his (the producer's) job.

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Management Problems Encountered with Livestock Guarding Dogs on the University of California, Hopland Field Station[1]

Robert M. Timm and Robert H. Schmidt[2]

Abstract.--Guard dogs are being promoted and utilized as effective predator damage control tools under a variety of livestock management conditions. We report our experience over 1 1/2 years with 5 dogs, primarily Anatolian shepherd and Akbash dog breeds. We discuss a number of behavioral and management problems we have encountered, some of which have not previously been reported in the literature. These include chasing vehicles and wildlife, predation on deer (Odocoileus hemionus columbianus), and incompatibility of dogs with other predator damage control methods.

INTRODUCTION

Since the early 1970s, guard dogs to prevent or reduce predation on sheep have received increasing attention in North America (Coppinger et al. 1983; Green et al. 1984; Linhart et al. 1979). Most early reports dealt with use of guard dogs in fenced pastures, but later investigations showed potenial for guard dogs on open rangeland as well (Green and Woodruff 1983a). This report describes our attempts to use 5 guard dogs at the University of California's Hopland Field Station from November 1987 through March 1989.

The Hopland Field Station, in the North Coast region of California, is comprised of 2,168 ha containing grassland, oak woodland, and chaparral. Elevation ranges from approximately 150 to 915 m. The station is divided into 32 fenced pastures ranging from 6 to 263 ha in size. Most of the pastures are grazed by sheep annually. The location typically has mild, rainy winters and hot dry summers. Annual rainfall averages 90 cm/yr and occurs primarily between October and April. A detailed description of the site was provided by Murphy and Heady (1983).

Most of the sheep maintained by the station are Targhee. The flock usually contains approximately 1200 breeding ewes and 100 rams that are used primarily for research purposes. Studies completed or in progress at this location include such topics as sheep genetics, reproductive behavior, food habits, and response to various management strategies. Shed lambing in the main barn at the station headquarters begins in October and ends in January in most years. Lambs are held with ewes in the barn for a minimum of 48 hours before being turned out onto native annual range. Each animal is individually numbered at birth. Ewes and their lambs are also paint-branded to facilitiate documentation of loss. The station employs two full-time shepherds, who inspect all pastures containing young lambs daily.

Shearing is done in April, and surplus lambs usually are marketed in late spring. Because most sheep are used in one or more research projects, their actual value is substantially greater than market value for commercial Targhee sheep.

PREDATION LOSS

From 1973 through 1983, an average of 10.4% of the station's lambs and 3.8% of the ewes were killed annually by predators. A significant increase in the number of coyote (Canis latrans) kills occurred during this study period (Scrivner et al. 1985). Since 1983, coyote predation has become even more serious, and mountain lions (Felis concolor) have been responsible for additional losses. Domestic dogs (Canis familiaris) kill sheep periodically, and occasional kills by bear (Ursus americanus), bobcat (Lynx rufus), gray fox (Urocyon cinereoargenteus), and golden eagle (Aquila chrysaetos) occur as well.

Some probable reasons for the increasing predation are changes in management by surrounding landowners and an apparent increase in predator numbers. Adjacent ranches on three sides of the field station previously grazed sheep and conducted predator damage control, but no longer do so. Coyotes and, more recently, mountain lions appear to be more numerous in the area, based on visual sightings by field station staff and ranchers.

This level of predation loss has been experienced despite predator damage control efforts by federal or county Animal Damage Control personnel and field station staff. For controlling coyote

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depredation, trapping and snaring are the tools primarily used, but denning, calling and shooting, and sodium cyanide ejector devices (M-44s) have also been employed. Improvement of fences has reduced predation by domestic dogs in pastures closest to human habitations. Sound- and light-emitting devices have been employed for short periods of time to deter predation, but without substantial success.

GUARD DOG ATTEMPTS

We began acquiring guard dogs in November 1987 in an attempt to determine their potential effectiveness at the field station. A brief history of our experience with each of 5 adult guard dogs is as follows.

Dog 1 - "Rex"

A reproductively intact, 2-year-old male Akbash dog was purchased from a breeder in November 1987. The dog was a proven, working dog that had previously protected herded sheep on rangelands in Colorado, under the supervision of shepherds who remained with the flock. Following an initial orientation period of several weeks during which the dog was penned in the headquarters area, the dog was placed in an 85-ha pasture (Watershed II) containing sheep. Despite several attempts to train the dog to stay within this pasture (including periodic chaining of the dog to a sheep shelter and provision of a source of dog food and water at the site), the dog preferred to roam throughout the entire lower-elevation portion of the field station (approximately 700 ha). He was capable of jumping the typical livestock fences dividing station pastures and was consistently found with or near sheep, or traveling between pastures containing sheep. He was frequently seen at or near recent predator kill sites and would remain at such locations for several days before moving on. We speculate that this behavior may have prevented predation from recurring occurring at these locations, but this dog did not signficantly reduce total losses. Of 220 ewes and lambs grazed (November 19, 1987 through February 11, 1988) in the pasture where the dog's feeder had been placed, 10 lambs were known to have been killed by coyotes and 40 more were missing when sheep were removed from that pasture. This represents a total loss of 22.7 percent, most of which we attributed to predation. It became apparent that we either needed dogs that would remain within fenced pastures or with particular groups of sheep, or else we needed many more dogs to protect the area being grazed.

An additional concern developed almost immediately with Dog #1. He chased vehicles and wildlife. He routinely chased cars and trucks traveling along the county road that bisects the lower third of the field station (and provides the only access route to a neighboring ranch). Bicyclists have reported being chased. While our main concern was that the dog might be hit by a vehicle coming in the opposite direction during such a chase, the neighboring rancher and visitors expressed concern about the dog's aggressiveness, particularly when a vehicle contained a pet dog. The guard dog was also observed chasing Columbian black-tailed deer (Odocoileus hemionus columbianus) and jackrabbits (Lepus californicus), and was seen feeding on their remains. It became apparent that he was capable of catching and killing fawns, at least, after running them into a fence. Further, sightings of wild turkeys (Meleagris gallopavo) on the station, which had formerly been common, became rare. We suspect that the dog's activities influenced turkey distribution.

In early summer 1988, Dog #1 became incapacitated as a result of tick-bite paralysis. Following veterinary treatment, his conditions soon improved to normal. He was found to be infested with a large number of ticks, and after this episode more intensive efforts were taken to control ectoparasites on all of the guard dogs.

Dog #2 - "Whistler"

This 23-month-old intact female Anatolian shepherd was obtained in June 1988. Although she had apparently worked satisfactorily with livestock previous to our obtaining her, she was too young to be regarded as a proven guard dog. Upon receipt, we found her to be lethargic and suffering from an infection. Following veterinary treatment, her health improved steadily but she was extremely shy of people to the point that when released into a small pasture, she could not be approached or caught. She did not attempt to cross fence, but she showed little or no inclination to stay with sheep. Her behavior did not improve for several months, except for slight progress in allowing humans to approach.

Upon coming into estrus, she was bred by Dog #1 and had a litter of nine pups in late November 1988. During the last stages of pregnancy and during 6 weeks of nursing pups, she was caged in the headquarters area. During this time, the station was experiencing sheep loss because of coyote attack, but this dog was not available for guarding use because she was nursing pups.

After her pups were weaned, Dog #2 was placed in a 25-ha pasture (Watershed I) with 115 ewes and 225 young lambs, where she remained from December 1988 through March 1989. It appeared that her behavior had changed following whelping, inasmuch as she was more often observed with or near sheep than she had been before. During her time in this pasture, regular (usually daily) checks of this pasture revealed 14 confirmed lamb kills by predators (10 by coyotes, 4 by eagles). Several coyote-killed lambs were not fed upon, perhaps indicating that the dog disturbed the predator before feeding was initiated. One ewe died from causes not related to predation. When the flock was removed from this pasture in mid-March, 21 additional lambs were missing. This represents a total loss of 15.5% of the lambs, most of which we attributed to predation.

Dog #2 was subsequently moved into a series of smaller pastures where a rotational grazing exper-

iment was in progress. Here, the dog began to harass and chase sheep. On one night, she stampeded the sheep, causing them to tear down a fence and gain access to an experimental pasture. The next day, one ewe was killed apparently by being run to the point of exhaustion, and approximately 20 more sheep had wool pulled from their bodies. Dog #2 was immediately removed from the pasture and isolated in a pen at the headquarters area.

Dog #3 - "Misty"

This 2-year-old female Akbash dog was obtained as a proven, working range dog in mid-September 1988 from the same breeder as Dog #1. She had recently borne her first litter of pups. Upon release, she began traveling with Dog #1 throughout the field station, jumping fence without difficulty. The pair began ranging more widely than did Dog #1 alone. On several instances, they were observed on properties adjoining the field station. Once they were apprehended approximately 1.5 kilometers outside the station's boundary, where they were captured by a landowner and returned to the station headquarters.

Dogs #1 and #3 occasionally appeared to patrol alone, but both often were observed at the site of a recent predation event, and both would stay at the location for several days. As with Dog #1 alone, the presence of this pair seemed to prevent subsequent predation at that location.

During the fall of 1988, Dogs #1 and #3 were observed together chasing, killing, and consuming deer fawns. During November and December, they were seen to kill at least one fawn per week. Their behavior and demeanor following verbal reprimands and scolding indicated that the dogs knew they should not chase deer, yet this behavior persisted when the dogs were not closely supervised. After mid-winter, fewer fawns were killed. We think this was due to the fawns having attained sufficient size that they could jump fences more easily and in general avoid the dogs more effectively.

Dog #3 came into heat in early winter and was penned at headquarters to avoid pregnancy. During this time, Dog #1 stayed near the pen for the duration of her estrus cycle and thus became less effective in preventing predation during this time.

Dog #4 - "Brutus"

This neutered 2-year-old male Anatolian shepherd was donated to the field station by a private party. He had regularly killed poultry, geese, skunks, domestic cats, etc. on the small acreage where he was penned with goats. In addition, his persistent barking during the night had generated complaints.

Dog #4 was released into a fenced, irrigated 10-ha pasture containing yearling rams. On occasion, he was observed to display rough play behavior toward the sheep. In three known incidents, he prevented dog attacks on this group of sheep. He has shown excellent attentiveness to sheep, and has been aggressive to strangers. We attribute his success not only to his individual behavior, but also to his placement in this relatively small, flat pasture that is topographically atypical of the station's rangelands.

Dog #5 - "Snow"

This female 2-year-old Great Pyrenees was purchased from a Nevada sheep ranch that uses approximately 30 guard dogs with herded bands. She was pregnant when received, and was housed at headquarters until her pups were weaned. Upon release into the field, she was intimidated by Dog #3 and therefore proved somewhat ineffectual. She would not remain with sheep, but returned repeatedly to headquarters where she spent considerable time. Her long coat may be inappropriate for California annual grasslands because it invites chronic problems with weed seeds including foxtails and other stickers.

SUMMARY OF PROBLEMS ENCOUNTERED

Jumping Fences/Straying Off Property

Green and Woodruff (1983a) report that it may be desirable for dogs to jump fences in order to protect sheep in contiguous pastures. In our situation we believe this behavior is disadvantageous. We think our dogs should stay with one band of sheep, or at least within one large pasture, as their effectiveness seems to be diluted when they travel considerable distances between dispersed groups of sheep. In such situations, coyotes or other predators readily adapt to attacking at times and places when the dogs are absent. Further, excessive amounts of time and energy can be expended in attempts to locate and check on the dogs when their whereabouts are now known. We equipped several of our dogs with radio transmitter collars, but we still expended considerable effort to find individual dogs and check on their well-being. Roaming is undesirable from an additional standpoint: dogs that stray beyond property boundaries are much more likely to be shot or hit by cars. Previous authors have noted the high mortality rate of guard dogs. Three of our five adult dogs roam at will throughout the field station. Currently, we have two of them caged because we believe they are in imminent danger of being shot if they cross onto a neighbor's ranch.

Chasing Cars and Cyclists

Green and Woodruff (1983b) report that 22 percent of guard dog deaths have been caused by collision with vehicles. Undoubtedly, some dogs have the inclination to chase vehicles, and we have not yet found a way to extinguish this behavior. Because two of our dogs (#1 and #3) have chased a neighboring rancher's grandchildren while on their motorscooters, they have been perceived as a safety threat and several complaints have been received about their behavior. As mentioned above, we caged them to prevent their being shot, should they again stray onto the neighbor's property. Although it is

heoretically possible to re-condition adult dogs by means of shock collars and continuous human bservation) to not chase vehicles or deer, in eality we have neither the time nor other resources o expend on such a training effort. Others who ave worked with guard dogs have suggested that we ould have fewer serious behavioral problems if we ad begun by raising guard dog pups rather than ttemting to adapt adult dogs to our situation. This also would involve a considerable commitment of ime and energy, as well as a lag time of perhaps 18 onths or more before the desired level of protection could be achieved. The only long-term solution pparent to us is to sell the adult dogs that isplay undesirable behaviors to a willing buyer.

Chasing and Killing Wildlife

While there are several reports that guard dogs ay chase wildlife such as deer, antelope, hares, tc. (Black 1981, Black and Green 1985, Green et al. 1984), we have found no reports of typical guard dog reeds having killed wildlife. Our observations of Dogs #1 and #3 regularly killing fawns, as well as ur suspicions about their harassment of wild turkeys, lead us to suggest that the impact of guard dogs on wildlife needs further study.

Some inviduals have suggested that our dogs' tendency to roam and to chase vehicles and wildlife is in part due to our providing them excess food. Apparently in some instances, guard dogs kept less well-fed have less energy and thus exhibit fewer such behavioral problems. We do not believe this is a solution, for several reasons. First, we monitor the nutritional condition of our dogs closely and, articularly in the warm months of the year, have ad a concern that they were not eating enough to aintain their physical condition. Also, we believe that several of our dogs would, if fed less dog food, simply kill and eat more wildlife.

Behavioral Changes During Reproductive Cycles

Male guard dogs are sometimes castrated to reduce their tendency to wander and to follow estrous females (Black and Green 1985, Green et al. 1984). However, it is not generally appreciated that intact guard dogs will periodically be ineffectual because of reproductive activities, as we ave observed. Further, because of behavioral and hysiological similarities between coyotes and dogs, we speculate that an estrous guard dog might attract coyotes, or that conversely an estrous coyote might interfere with the desired guarding behavior of a ale guard dog.

Changes in Sheep Behavior Toward Dogs

Green and Woodruff (1983a) indicate that sheep learn to respond to individual dogs, and thus the use of guard dogs appears not to create behavioral roblems among sheep. Yet, our station's shepherds bserved that sheep became more complacent in the presence of herding dogs following their adaptation to the guard dogs's presence. Although this problem appears not to be widespread or serious, it can result in increased time and effort being needed to gather and move sheep that no longer responded as easily to herding dogs.

Incompatibility with Other ADC Tools

Surprisingly little has been written about the incompatability of guard dogs and other common predator damage control measures such as traps, snares, and M44 cyanide ejectors. While in theory it might be possible to train guard dogs to avoid scented M44s, not many ranchers would be willing to risk losing a guard dog as a result of using these devices in the vicinity. While it might also be possible to train guard dogs to avoid traps or snares, the potential for catching the dogs remains wherever these tools are placed. Unless the rancher knows the location of all traps and snares, and also has the time to check these whenever a guard dog is unaccounted for, a potential risk remains. This problem is further compounded when guard dogs cross fences and do not remain in predictable areas, but roam widely. Thus, the choice to employ guard dogs might also be a choice not to employ traps, snares, or toxicants, at least not in the immediate vicinity of the dog.

SUMMARY

Green and Woodruff (1983b) noted that some limitations on effective guard dog use include arid climates, widely-scattered livestock, rough terrain and heavy vegetative cover, and abundant predators providing severe pressure. While this description is appropros to the Hopland Field Station, it also is quite descriptive of most of the rangelands in the North Coast of California, traditionally one of the country's most important sheep-producing regions.

It is our experience, after working with a total of 5 guard dogs during these past 1 1/2 years, that they have limited effectiveness. Only one of our dogs is doing the type of job with which we are uniformly pleased; this, despite the fact that most of the dogs were proven working adults at the time we obtained them. From November 1987 through March 1989, we have expended approximately 500 person-hours of station labor (valued at $10.07/hr), in addition to expenditures totalling some $2500 for purchase and shipping of dogs. This does not include expenses for veterinary care, licenses, food, and other items necessary to the maintenance of the dogs. Unfortunately, the extent of problems we have encountered, especially considering our use of more and better-skilled labor than the average ranch, indicates to us that guard dogs are not a viable solution (either practically or economically) except in limited instances in our geographic area. We wonder whether our predator losses would have been more effectively reduced had we spent our time and funds on conventional control tools and methods.

We would like to see further evaluation of the problems outlined above, and we intend to continue research on guard dogs in order to find means to solve some of these difficulties. A better understanding of the situations in which guard dogs will work effectively, and a fuller appreciation of some of the problems they create, will allow ranchers to make better decisions when planning a predator control strategy.

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Black-Footed Ferret Recovery[1]

Dean E. Biggins[2] and Ronald A. Crete[3]

Abstract.--The captive population of black-footed ferrets (Mustela nigripes) increased from 24 to 58 animals in 1988, and was split to provide the species added protection against extinction. Experimental reintroductions may begin in 1991. In some areas, "experimental population" designations as authorized under Section 10(j) of the Endangered Species Act may be used to provide wider management latitude. The Black-footed Ferret Interstate Coordinating Committee oversees much of the work related to reintroduction. Expanded effort to locate wild ferrets now includes a $10,000 reward offer. Research focuses on captive breeding, reintroduction techniques, disease, and habitat. A new Recovery Plan was approved in 1988.

INTRODUCTION

The black-footed ferret (Mustela nigripes), a weasel-like animal closely related to two species of Eurasian polecats, was listed in 1967 as an endangered species in the United States (Federal Register 32:4001, 11 March 1967). Biggins and Schroeder (1988) reemphasized the black-footed ferrets's dependence on prairie dogs (Cynomys spp.), and reviewed landmark events in recent ferret history, culminating with a brief description of status in 1987. Captive propagation of ferrets caught in Wyoming was just beginning, and its success improved in the years following.

The Black-footed Ferret Recovery Plan was completely revised in 1988 (U.S. Fish and Wildlife Service 1988), reflecting emphasis on captive propagation and reintroduction and incorporating the Wyoming Game and Fish Department's Strategic Plan (Wyoming Game and Fish Department, 1987). The current strategy for this recovery effort involves captive propagation of ferrets followed by reintroduction into secured habitats across the species' range in the next 10-20 years. New goals set target levels of 200 breeding adults in captivity by 1991 and 1500 free-ranging breeding adults by the year 2010. Further, there should be at least 10 wild populations with at least 30 adults each, and wild populations should be distributed over the widest possible geographic area (consistent with the historic range of the species). The species will be eligible for downlisting from endangered to threatened status if these criteria are met and the rate of subpopulation establishment is at least as high as the rate of subpopulation disappearance for a period of 5 years. The amount of habitat needed (prairie dog colonies) for 1500 breeding adult ferrets is estimated at 75,000 ha (185,000 ac). About 0.4-0.8 million hectares (1-2 million acres) of prairie dog habitat remain in the United States but much may be unsuitable for ferret reintroduction (Minutes of the Black-Footed Ferret Interstate Coordinating Committee, 8-9 March 1988). Requirements for delisting have not been established.

The remainder of this paper is devoted to describing the present status of black-footed ferret recovery efforts and reviewing the tasks that are faced in the near future. The revised Black-footed Ferret Recovery Plan (U.S. Fish and Wildlife Service 1988) places tasks into the following five groups: 1) captive propagation, 2) location and

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evaluation of habitat, 3) location of additional ferrets, 4) reintroduction, and 5) management of free-ranging populations. Of 190 tasks and subtasks identified, 67 were assigned to the "research" category. All five groups of tasks have investigative and operational elements, and it is imperative that researchers work closely with groups involved in implementing the recovery strategy. The U.S. Fish and Wildlife Service (Service) Division of Fish and Wildlife Enhancement, under the Director of the Denver Regional Office (Region 6), has been delegated lead responsibility to organize and implement a national strategy for recovery of the black-footed ferret. The National Ecology Research Center, within the Service's Research and Development arm (Region 8), conducts or coordinates most Service-sponsored research on the ferret. A 6th group of tasks in the Plan focuses on organizational arrangements that will facilitate work specified in groups 1-5.

CAPTIVE PROPAGATION

Captive propagation of ferrets is a cooperative venture of the Wyoming Game and Fish Department, the U.S. Fish and Wildlife Service, the Henry Doorly Zoo, and the National Zoological Park. The core breeding population is managed by the Wyoming Game and Fish Department in a specially constructed building at their Sybille, Wyoming research facility. Primary funding is provided by the Service from authorizations under Section 6 of the Endangered Species Act of 1973. The six ferrets in captivity in 1986 produced no offspring. Twelve more wild-caught ferrets were added to the captive population in 1986 and early 1987, and 2 of the 11 captive females produced 7 young in 1987. In 1988, 34 kits were weaned from 13 litters produced by 14 females, but an adult female died that year. The total population thus has grown from 18 to 25 to 58 in two breeding seasons, and the program is on schedule. All known black-footed ferrets are in captivity.

By 1991 up to five captive breeding populations in three or more facilities may be established. The parent genetic stock will be maintained at the Wyoming facility while the satellite facilities will be established with young from subsequent generations. The satellite facilities are to be financially self supporting, therefore not requiring additional funds for captive breeding (Wyoming Game and Fish Department 1987). To provide protection against extinction from a single catastrophic event, the population was split following the successful breeding season of 1988. Genetically representative young-of-the-year were sent to two additional facilities; the National Zoological Park's research facility in Virginia received seven ferrets and the Henry Doorly Zoo in Omaha, Nebraska received eight ferrets. The captive breeding phase can be deemphasized after about 10 years, although a small facility may be needed to augment wild populations destroyed by canine distemper or other events.

Much of the research in captive breeding has focused on developing techniques to maximize reproductive output and retain as much genetic diversity as possible. Topics under investigation include collection and cryopreservation of gametes, artificial stimulation of the reproductive cycle, artificial insemination, in vitro fertilization and embryo transfer, methods of detecting estrus, and genetic variability. Cooperating institutions are the University of Wyoming, University of Idaho, National Zoological Park, National Cancer Institute, and the Wyoming Game and Fish Department. In addition, a study of the nutrition of captive ferrets is being conducted by the Bronx Zoo. The National Ecology Research Center coordinates and funds most captive propagation research.

LOCATION AND EVALUATION OF FERRET HABITAT

Remaining potential habitat (prairie dog colonies) for black-footed ferrets has not been accurately estimated. Because of the success with captive breeding, there is increased emphasis on locating ferret habitat. This large effort presently encompasses 12 states, 2 Canadian provinces, and Chihuahua, Mexico. In 1987, the Service (Region 6), invited representatives from state conservation agencies, Service field offices, and several land management agencies throughout the ferret's historic range to attend a meeting to discuss the search for habitat and other aspects of ferret recovery. The resulting group, now known as the Black-footed Ferret Interstate Coordinating Committee (ICC), promotes formation of state working groups and is a mechanism through which the Service receives information to debate, design, and document national-level recovery strategy. In addition, the ICC committee serves as a valuable sounding board for conflicts and barriers to ferret recovery. Representatives of the ICC are members of state-level

committees and communicate directly with state working groups on direction and guidelines devised and concurred upon at ICC meetings. Managers of the captive breeding program attend ICC meetings to advise on the probable timing of reintroductions and to obtain information on the status of habitat evaluations and preparations.

Researchers are working closely with ICC members to develop a system to evaluate the quality of potential reintroduction sites. Ranking sites with the evaluation criteria will help determine the order of reintroductions. The first national-level ranking of reintroduction sites is scheduled for December 1989. States and the Service will then work cooperatively with private and public land managers to develop management agreements and special rules for selected habitats and reintroduction of ferrets. At this time, no sites are managed for ferret reintroduction. Management will involve long-term commitments from state and federal agencies and negotiated agreements with numerous private land managers. Long-term easements may be necessary to compensate affected cooperating landowners.

During the next several years, the Service, states, and other federal agencies will be locating and mapping prairie dog complexes of sufficient quality to be considered for ferret reintroductions. Subsequently, states are proposed to be partitioned into three zone categories: 1) potential reintroduction habitat (black zones), 2) areas that support prairie dog populations, but lack sufficient data to evaluate them as potential reintroduction habitat (gray zones), and 3) areas where quality of prairie dog colonies is too low to warrant a ferret reintroduction effort (white zones). The white zones, encompassing much of the area in the western states with potential ferret habitat, could eventually be block cleared, indicating they would not require further ferret survey clearances for land use proposals needing Federal agency permits or funding. This zone concept does not mean that the Service, states, or other agencies support the eradication of prairie dogs in block-cleared white zones. Prairie dog colonies are an ecological community supporting an abundance of wildlife and plant species, and states are encouraged to develop management plans for prairie dogs in all three zones.

Black-footed ferret survey guidelines promulgated by the Service in March 1989 open the opportunity to begin block clearing complexes of prairie dog colonies under 400 ha (1000 ac) that have no potential for ferret reintroduction. In addition, these guidelines provide a mechanism to exempt surveys where complexes of white-tailed prairie dog (Cynomys leucurus) and Gunnison's prairie dog (C. gunnisoni) colonies are less than 81 ha (200 ac) or complexes of black-tailed prairie dogs (C. ludovicianus) are less than 32 ha (80 ac). These changes were brought about by research findings on ferret habitat requirements. Guidelines are available from Service field and state offices across the historical range of the ferret; Service personnel at these offices should be consulted for more information on the need for surveys.

LOCATING ADDITIONAL BLACK-FOOTED FERRETS

Genetic variability is low in the captive population of black-footed ferrets (O'Brien et al., in press), and finding any remaining wild ferrets would enhance the program. Search effort increased after the demise of the Meeteetse, Wyoming population in 1985-86. A $5,000 reward in Montana (sponsored by the New York Zoological Society) expanded to most other states in the ferret's range by 1988, and the offer was increased to $10,000 in 1989. The ICC recommended development of state contingency plans dictating the course of action if ferrets are located; most states have approved plans in place. Ferret reports are investigated by state conservation agencies and Service field offices. The National Ecology Research Center has maintained a response team to conduct follow-up work on good quality reports and to monitor and capture ferrets if necessary. No new ferret populations have been located despite the increased effort. Research effort focuses on improving methods to locate ferrets, including current studies on feasibility of aerial surveys for detecting sign in winter and studies of prairie dog burrow plugging/ferret digging relationships.

REINTRODUCTION

By the early 1990's, reintroduction will require much of the resources now devoted to other aspects of ferret recovery if captive propagation remains on schedule. Experimental reintroductions are being planned first for the Meeteetse, Wyoming area to test reintroduction protocol and to

reestablish reproduction in the wild as soon as possible. Additional sites selected by the Service and state conservation agencies will receive ferrets that are in excess of the needs of the captive breeding program as soon as they are available. The Service plans to use the flexibility provided under Section 10(j) of the Endangered Species Act to designate reintroduced captive-raised black-footed ferrets as "experimental populations" wherever practicable and prudent. When reintroduced populations of ferrets begin to produce excess offspring, these offspring can be translocated to other reintroduction sites, helping reduce costs of and dependency on captive breeding programs.

Presently, most reintroduction activities are research-oriented. Two laboratory studies are beginning that will address the benefits of submitting ferrets to pre-reintroduction experience (training) in hunting, killing, and predator avoidance. A second phase of experiments will use results of the training phase in actual field trials. A closely related animal, the Siberian polecat (Mustela eversmanni), will be used in these first two phases; the final phase will be experimental reintroduction of black-footed ferrets. The experimental release of Siberian polecats closely parallels a study of California condor (Gymnogyps californicus) release and monitoring techniques using Andean condors (Vultur gryphus) as the investigational surrogate. Close monitoring of the first black-footed ferret reintroductions will be essential, and improved radio-telemetry techniques for monitoring will be tested on Siberian polecats. Canine distemper is a hazard to wild and captive ferrets (Carpenter et al. 1976, Forrest et al. 1988, Williams et al. 1988), and research is underway to develop an effective vaccine and practical means to administer it. Another study will attempt to assess the prevalence of canine distemper in other species of wild carnivores to gain insight into the probability of exposure of reintroduced ferrets. Reintroduction-related research is being conducted by biologists at the National Zoological Park, Wyoming Game and Fish Department, the University of Wyoming, the Wyoming Cooperative Fish and Wildlife Research Unit, and the National Ecology Research Center, primarily with funds administered by the Service.

MANAGEMENT OF FERRET POPULATIONS

Presently, there is almost no activity (operational or research) in this category. Future needs include development of monitoring strategies for ferrets, prairie dogs, and diseases, and refined plans for restocking and translocation to maintain genetic diversity and solve demographic problems.

ORGANIZATIONAL ARRANGEMENTS

This portion of the Plan suggests formation of technical and policy advisory groups to assist in developing effective solutions to the diverse challenges of ferret recovery. Working groups, public relations, education, communication, and funding are also addressed in this category. Examples of advisory groups include the Black-footed Ferret Advisory Team, which counseled the Wyoming Game and Fish Department on management and research of the Meeteetse population, and the Captive Breeding Specialist Group of the International Union for the Conservation of Nature and Natural Resources, which provided valuable assistance during the early stages of captive propagation. The ICC and state working groups were effective organizational arrangements discussed previously.

CONCLUDING REMARKS

The captive breeding program for ferrets has been highly successful, suggesting an optimistic prognosis for ferret recovery. Although it is essential, excellent captive production of ferrets does not assure recovery of the species; the greatest challenges may lie ahead. We speculate that a combination of factors led the black-footed ferret nearly to extinction--perhaps due to the synergism of severe habitat reductions (caused by prairie dog poisoning campaigns and sylvatic plague) coupled with canine distemper in the ferrets (Biggins and Schroeder 1988). We wonder, nevertheless, how much importance to ascribe to each problem, and even whether we have correctly identified all of the problems. If we understand the problems, can they be solved or mitigated? The opportunity to learn directly through hands on research of wild black-footed ferrets vanished with the animals, but the search for explanations continues. A careful evaluation of the behavior, ecology, and genetics of the highly successful Siberian polecat, the black-footed

ferret's closest living relative, should provide a different perspective from which to interpret the black-footed ferret's decline. It is also imperative that the first reintroductions of ferrets be carefully designed studies, because understanding the reasons for any failures may be crucial to ultimately achieving success.

ACKNOWLEDGEMENTS

We thank everyone who has contributed to the black-footed ferret conservation effort. Unfortunately, space is too limited to mention everyone by name, and to single out individuals does disservice to those not named. We appreciate the foundation laid by those who studied ferrets in South Dakota and first attempted captive propagation. A diverse group of researchers at Meeteetse was able to build on that foundation. We are deeply indebted to the managers of the present captive propagation project in Wyoming for rebuilding ferret numbers (and our hopes for the species), to the zoos now contributing to that endeavor, and to the project's advisors. Participants in the evolving cooperative venture leading toward ferret reintroduction include state and federal agencies, private conservation organizations, private landowners, industrial developers, and universities. The team approach is indispensable; perhaps the cooperation exemplified here provides a new connotation for the term recovery team.

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An Assessment of the Urban Wildlife Problem[1]

William D. Fitzwater[2]

Abstract.--Basic urban wildlife problems include: proper identification of species, shift from agrarian to urban society, different interpretations of humaneness, compassion for individual rather than a population as a whole, and public ignorance of urban pest management. Positive values are esthetics and environmental education opportunities. Negative values are disease transmission, life/injury-threatening situations, damage to buildings/other property, water structures/quality, petty annoyances, and indirect economics.

Modern civilization has created artificial habitats. Most other life forms have been walled out of cities except for animals dominated by humans, such as, cats, dogs, caged birds, and exotic fish or those who have adapted to humans so well they have become pests, such as, commensal rats/mice, pigeons, starlings, and house sparrows. As urbanization continues to gobble up more and more living space, evicting other forms of life, we can expect urbanite-wildlife interactions to increase.

SOME CONCEPTS ABOUT NUISANCE ANIMALS IN URBAN ENVIRONMENTS

Identification of nuisance species

There are some 1,100 species of birds and 467 species of mammals present in North America. While less than 2% of these are urban pest species, the ignorance of the urban populace concerning the identification of their "pests" is appalling (Dagg 1974). One woman caught and released in a nearby park some "...eight naked-tail squirrels." (known in the trade as "roof rats") (Whitten 1979). Muskrats are frequently described as very big sewer rats; while effective controls for moles are quite different from pocket gophers, few householders know which they have; some ADC specialists called in to trap gophers ended up with a large, angry armadillo; "starlings" poisoned with treated rice on a Texas courthouse turned out to be cowbirds. Some animal groups, like bats and reptiles, are generally greeted with repulsion, but most wild animals are "cute" until their paths cross those of the urbanite.

Shift from Rural to Urban Society

Since World War II this country has seen a shift from an agrarian society to one predominately urban in its thinking. Surveys have shown a rural society is more tolerant of other animals and willing to share some of their living space with them (O'Donnell & VanDruff 1983). The urbanite, never having had to wrestle basic life needs from the earth, panics when encountering a "wild" animal he can't control. The thought of sharing the house with a mouse is repulsive. On the other hand, the coyote is a friendly dog that lives in a Disney movie or paces the concrete pads in the local zoo. He cannot understand why so much money and effort is being spent to limit coyote numbers in the "out-of-doors".

Different Interpretations of Humaneness

While people may advocate humaneness to other animals, this attitude changes when they are directly challenged. One woman called the Extension Service for help in ridding her fireplace of a colony

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of swifts (Anon. 1988). Their flapping wings were spreading ashes all over her living room. She became so desperate she lit a fire in the fireplace but found, "You could smell burning feathers, but they still wouldn't leave." Now this woman would not dream of hurting an animal but she set fire to a bird because it was causing a mess in her living room.

This variable sensitivity to "humaneness" is also shown in the matter of who is the victim. There is little interest in the agonizing death of a lamb in the jaws of a coyote, but if that same coyote is seen trotting down a city street with a freshly-killed house cat in its mouth that is "inhumane" (Howell 1982). Despite public approval of the animal rights' philosophy - - "all animals have rights" - - the urbanite doesn't actually believe all animals have equal rights. Thus he sees no parallel between his desire to eliminate the mouse and the rancher's desire to eliminate the coyote.

The urbanite is horrified at the continued use of the leghold steel trap. The occasional raccoon or squirrel that gets into the attic can often be taken in a live trap so he cannot understand why leghold traps have to be used in the wild. The gap between the technology of going to the moon and developing a painless, BUT effective and practical, trap for field use is not understood.

Poisoning is another dreadful happening. Poisons are associated with a theatrical thrashing about of a victim in terrible pain. This rarely occurs as modern pesticides affect body chemistry and nervous systems in more subtle ways than the metallic toxicants of several decades ago. Poisoning, compared with natural causes, is generally the most humane way for the majority of nuisance animals to go.

Compassion for the Individual

Conditioned to a great extent by Disney make-believe, there is great empathy for the individual. For example, the rescue of two out of three California gray whales trapped in the Arctic icepack has no practical significance on the whale population in the Pacific. The $million plus spent in their rescue could have been better utilized in research on improving status of world whale populations.

While expensive capture and translocation of individual animals from a habitat where they are not wanted or are so numerous they endanger the welfare of that habitat is acceptable (Hadidian, et al 1988), the fact is most transplants are disasters ending in the early death of the transplanted individuals and/or disruption of the new environment in which they were placed. Of 300 eartagged raccoons released in North Carolina at a cost of $15,000, only 16% survived (Boyer & Brown 1988).

Urban Pest Management

More research needs be directed to the problem of urban pest management. The methods in place today are those developed from agriculture. Urban animals due to the largess of urbanites are generally well-fed and more difficult to trap. The use of toxicants in urban vertebrate pest management needs closer scrutiny. Habitat modification is the most effective method of control, but is not popular as it involves the urbanite doing something physical and expensive. Wild animals do not honor human boundaries so while an individual might encourage their presence, neighbors may be very hostile.

Further research needs be done on the life histories of urban animals. Heavier densities are found in species, like squirrels (Flyger, et al 1983) and raccoons (Schinner & Cauley 1974), in urban habitats versus free-ranging animals in open habitats. There is also the need to adapt control measures to conform with city ordinances and wildlife agency codes. The inability to recognize the species of animal involved could lead to a conflict with State wildlife codes as the average homeowner recognizes no restrictions on methods used in solving personal problems. While these attitudes can be changed (Timm & Schemnitz, 1988), we are not doing a good job in this area.

POSITIVE VALUES OF URBAN WILDLIFE

Esthetics

The urbanite is thrilled by fleeting contacts with wild animals in the asphalt/concrete habitat - - unless it is a rat or skunk. Sparrows hustling in the streets and pigeons gliding between tall buildings revive the deeply buried tie between man and lower animals that our forefathers understood.

Environmental Education

Psychologists believe contact with lower animals encourages the development of intellectual and social competence as

well as physical development. Children flock to a petting zoo to have contact with living "toys".

When we discuss "urban wildlife" we are actually dealing with two separate habitats - the "inner city" and the suburbs. While inner city inhabitants could undoubtedly benefit from more contact with wild species, this paved over area offers little refuge for them. Until more natural areas are developed in inner cities, there is little hope much good can come from wildlife contacts in those areas. Suburban habitats are entirely different and will continue to be the site of most urban-wildlife conflicts.

NEGATIVE ASPECTS OF URBAN WILDLIFE

Health

The ubiquitous commensal rodents, i.e., the house mouse, Norway rat, and the roof rat, are the biggest threat to human health as they serve as vectors and reservoirs for many harmful pathogens including:

Amebiasis, Chargas disease, Dwarf tapeworm, Echinococcosis, Endemic relapsing fevers, Histoplasmosis, Leptospirosis, Lymphocytic choriomeningitis, Murine typhus, Plague, Rabies, Rat-bite fever (Haverhill), Rat-bite fever (Sodoku), Rat mite dermatitis, Rat tapeworm, Rickettsialpox, Rocky Mountain spotted fever, Salmonellosis, Schistosomiasis, Sporotrichosis, Toxoplasmosis, Trichinosis, Trichophytosis, and Tularemia.

Pathogenic organisms associated with other avian and mammalian species of wildlife in the urban habitat include:

Aspergillosis (Thrush), Canine distemper, Cryptococcus, Ectoparasites, Encephalitides, Giardiaosis, Histoplasmosis, Leptospirosis, Listerosis, Lyme disease, Newcastle disease, Ornithosis, Plague, Rabies, Raccoon roundworm, Salmonellosis, Toxoplasmosis, and Tularemia.

Life/Injury-Threatening Situations

Besides disease transmission, wild animals can aggressively threaten humans by biting and scratching. Humans have also been killed by alligators, bears, commensal rats, coyotes, dogs, mountain lions, and poisonous snakes in suburban situations. Coyotes, in particular, adapt to human-caused environmental changes to the point this species has become a threat to children in certain areas (Howell 1982). Humans have been killed as a result of collisions between automobiles and deer or dogs and in aircraft with birds, coyotes, and deer. Still another cause are fires started by rodents gnawing on wires or pigeons carrying burning materials into flammable nests (Fall & Schneider 1969).

Property Damage to Buildings

Physical damage through the gnawing activities of rodents, such as, rats and mice (both commensal and native species like pack rats and deer mice), and tree squirrels can result in expensive damage. Squirrels and raccoons join these animals in ripping up insulation for nesting material, chewing holes in siding or walls to gain entry, splintering window frames in a frantic attempt to escape, and cause water damage from holes gnawed in lead or plastic water pipes.

Damage can also be done to the outside of buildings where the acidic accumulations of pigeon feces erode metal drains and limestone building blocks. Nesting, signalling, or territorial activities by woodpeckers result in damage averaging $300 per home (Craven 1984). The mud nests made by industrious swallows under the eaves are unattractive to the neat householder. Loose feathers and nesting material from pigeons and sparrows plug the vents of airconditioners and drains. This action resulted in over a $100,000 loss with the collapse of a flooded department store roof in Santa Barbara, Calif. (Gilman 1978).

Other Property Damage

The branch of the Federal government assigned the task of reducing wildlife damage is currently in the U.S. Dept. of Agriculture, Animal & Plant Health Inspection Service, Animal Damage Control (APHIS-ADC). They have a computerized program providing monetary data on the damage caused by wild animals. Data from two States, California (Thompson 1987) and New Mexico (Nunley 1987) for Fiscal Year 1987 indicates the extent of these losses:

STATE	BUILDINGS	GROUNDS	OTHER PROPERTY
Calif.	$43,727	$71,642	$91,682
N.M.	$ 7,310	$21,653	$ 4,970
Total	$51,037	$93,259	$96,652

This total of $240,948 annually represents only part of the cost of wildlife damage to property in these two states. It does not include the costs of

ontrol measures taken to reduce these osses or those losses not brought to the ttention of APHIS-ADC. Whitten (1979) eports an earlier APHIS-ADC compilation or Texas in FY 1978 gave a total of 154,196 for rural losses compared to 197,838 losses in 11 of the largest ities in the State.

Probably one of the greatest losses s in landscape damage. One must consider ot only the replacement cost, but the ime lost. Trees and ornamental shrubs re barked by squirrels, deer, rabbits, eadow mice, beaver, wood rats, and orcupines. White tail deer alone in estchester County (N.Y.) cost homeowners rom $6.4 - $9.5 million PLUS an dditional $1.2 to $1.6 million in ttempted control measures (Connelly, et l 1988). Such species as, raccoons, tree nd ground squirrels, mice, muskrats, oyotes, chipmunks, armadillos, deer, abbits, woodchucks, and moles that keep ruck gardeners awake nights can also reck havoc on a city garden or flower ed.

Other target areas are lawns and golf reens. Raccoons, skunks, ground quirrels, and woodchucks dig into them; oles and pocket gophers burrow under hem; coots and Canada geese graze them losely. The geese and coots also eposit a high-powered fertilizer creating golf hazard not covered in the rule ook. The extent of this problem was nvestigated by Conover (1985) who found t least 26% of golf course managers in he Northeast had such a serious problem hey would gladly pay an average of $444 o reduce it. Animal waste products can ause unsightly burn spots in the egetation under heavily populated lackbird-starling roosts.

The food and environs in city zoos is qually attractive to wild animals who eat nd contaminate food, destroy ornamental lantings and buildings, and carry iseases. In a survey of zoological ardens 59% admittedly had problems. ontrol efforts cost an average of $6,500 nnually per zoo (Fitzwater 1988).

DeGrazio (1978) reported utility pole amage by woodpeckers cost the Bell elephone Co. $441,000 annually. quirrels and roof rats gnaw on overhead able lines causing power outages. ransformers and crossarms on cable ystems are attractive nest sites for quirrels and raptores also resulting in ower outages. A study (Hamilton, et al 988) estimated squirrel-caused outages nnually cost power companies in Lincoln Neb.) $23,764 and in Omaha (Neb.) $47,954. When squirrel guards were placed in Lincoln at a cost of $260,000, annual losses were reduced 78%. Pocket gophers work underground on these cables too.

Water Structures and Quality

Burrowing by muskrats and nutria weaken water-retaining structures, causing cave-ins, washouts, and loss of stored water (DeAlmeida 1987). Dams built by beaver plugging culverts and drainage ditches result in flooding of roads, levees, pasture land, agricultural crops, and forests. Timber loss alone has been estimated at $17 million annually in Mississippi and $23 million in Arkansas (Wigley & Garner 1987).

The quality of drinking water has been lowered for city-dwellers where gulls, geese, and other waterfowl concentrate in water reservoirs. A protozoan parasite, Giardia lamblia, from the bladders of beaver is becoming an increasing problem. Minor disturbances include frogs, snakes, and mammals falling into swimming pools and depredations on ornamental fish in backyard pools by raccoons.

Petty Annoyances

The unesthetic effects of animal feces is undeniable. The mess created by pigeon, sparrow, starling, blackbird, and bat roosts can accumulate on/in buildings causing odor, slipperyness, and health problems. The aroma of a disturbed skunk remains an unpleasant memory long after the incident has passed. The removal of dead animals from the streets after an accident is not a high priority of city governments.

One form of loss that really riles urbanites is a pet cat or dog becoming a meal for a hungry coyote. Neither are they happy about pets fighting possibly rabid raccoons or the consumption of pet food by wild animals. Where poultry are raised within city limits, they must be tightly caged to protect them from raccoons, skunks, opossums, weasels, fox, and coyotes.

Nothing human is sacred to these non-human species. Burrowing animals like woodchucks, pocket gophers, and moles puttering around in cemeteries have brought up remnants of dead humans. The writer once had to scare a Chihuahua raven congregation away from a cemetery as the mourners confused them with vultures having sinister intent.

From the disruption of individual garbage cans to city dumps, urban garbage is another source of annoyance. Raccoons, crows/ravens, dogs, and rats are the chief offenders at the householder's garbage cans. At dumps, rats have long-standing proprietory rights, but bears, gulls, pigeons, and starlings have become frequent and more visible visitors.

Mississippi kites harass humans in certain sections of the country (Parker 1988). While this is only protection of the kite's "nesting territory", humans tend to resent any non-human claims to the same space. Mocking birds are sometimes similarly protective, but, outside of making the family cat miserable, are rarely as menacing as the kites.

There is no wakeup alarm more aggravating than the plaintive cry of a mourning dove under your bedroom window at an ungodly hour. Woodpeckers, too, sometimes choose the early morning to start up their signal drumming on the siding wall next to your bed. The chatty conversation of starlings/blackbirds roosting in trees around the house is doubly annoying - first when they arrive at night and when they leave early the next morning. One New York resident who refused to let authorities remove a communal nest of new South American immigrants, monk parakeets, called two weeks later begging them to take them, please, and give his eardrums a rest. Among the annoying night noises is the ghostly parade of rats, mice, bats, raccoons, and flying squirrels around the attic.

To the individual who sets a feast for song birds in his back yard, it is frustrating to find it disappearing in the mouths of what he considers undesirable aliens, such as, rats, squirrels, jays, house sparrows, and starlings

Indirect Economic Losses

Wildlife damage to farm and forest production cost city-dwellers indirectly in the price of food and fiber (Nunley 1987 & Thompson 1987):

DOLLAR LOSSES TO AGRICULTURE FOR 1987

STATE	LIVESTOCK	AGRIC.CROPS	FORESTRY
Calif.	$404,152	$357,659	$25,595
N. M.	$255,884	$233,291	$12,115
Total	$660,036	$590,950	$37,710

This adds up to $1,288,696 annually for just <u>two states</u> plus the cost of animal damage control measures taken to reduce these losses. Bird damage to grain, sorghum, blueberries, and grapes amounts to $5.8, $1.6, $2.1, and $4.4 millions respectively in crop-growing areas annually (DeGrazio 1978).

We can't put a dollar value on the joy of seeing wild animals, but neither can we ignore the cost/benefit ratio of their presence.

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Urban Wildlife Damage: A Complex Problem[1]

Mark E. Mapston[2]

Abstract. Wildlife can create problems when they conflict with man's health or economic interests, or when their presence is a nuisance. Animals have had to adapt to a variety of environmental alterations thrust upon them by land development and urbanization. This has caused a closer association of some wildlife species with man. What were once mainly rural occurences can now be found taking place more and more in urban and suburban environments. An increasing amount of native and introduced wildlife species are coming into conflict with man --- not just limited to the typically thought of "urbanized" animals such as commensal rodents, squirrels, raccoons, opossums, and skunks. We now also have problems with larger predators, larger rodents, and others.

In order to effectively deal with these newer and increased number of wildlife damage concerns, it will take the combined efforts of civic, private, and state entities as well as the local wildlife damage control agency. Control efforts are largely dependent upon the particular animals involved and the complaint situation and locale.

INTRODUCTION

In recent years the urban and suburban wildlife damage problem has become much more complex. There is a continual expansion of urban and suburban areas into the rural community of our country. With this expansion, more and more native and introduced wildlife species are coming into conflict with man's health or economic interests, or their presence is creating a nuisance.

Animals have had to adapt to a variety of environmental alterations thrust upon them by land development and urbanization. This has caused a closer association of some wildlife species with man. These same animals have more than adequately overcome any difficulties they have faced in the urban and suburban environments and many wild animal populations are thriving in these communities. What were once mainly rural occurences of wildlife damage can now be found taking place more and more in our urban and suburban communities.

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. Marriott Hotel, Fort Collins, Colo., April 17-20, 1989.

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URBAN WILDLIFE DAMAGE

Animals can regularly be found raiding garden and trash containers, and eating and drinking from pet dishes from within the confines of a populated neighborhood. Other animals can be found rooting for food in yards and flower beds, while some are taking up residences in attics, barns, sheds, and underneath houses. An increasing amount of wildlife species are coming into conflict with man --- not just limited to the typical "urbanized" animals such as commensal rodents (*Mus musculus*, *Rattus rattus*, *Rattus norvegicus*), tree squirrels (*Sciurus* spp.), raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), and skunks (*Mephitis mephitis*, *Spilogale pretorius*).

We now also have problems with larger predators, exotic birds, bats, larger rodents, and reptiles in these areas as well. Complaints come into the state's animal damage control offices on a regular basis regarding problems associated with these different species.

PREDATOR DAMAGE

Larger predators have imposed themselves upon the urban and suburban scene in redent years. The most common complaints received are for the predation of demestic pets such as dogs, cats, chickens, ducks, geese, and the predation of urban or suburban livestock, or for the harassment of these animals, or the feeding on of pet food or garbage.

I have personally been involved with several cases of suburban predation problems. Some of the first direct control work that I did was for coyote (Canis latrans) predation of calves and sheep. In one case, coyotes had killed 8 calves on a small ranch located on the city limits of Wichita Falls, Texas during the winter of 1981-1982. Traditional coyote control methods were employed and 5 coyotes were taken off of the ranch and the predation was stopped.

In another situation, predators were responsible for the loss of 50 head of lambs, 1 ewe, and 1 calf on the city limit boundary of Olney, Texas. This represented an economic loss of $3583.00 to the rancher who was dependent on this ranching operation for his livelihood.

Other Texas Animal Damage Control personnel have related similar complaints and have had to deal with larger predators in the urban/suburban locale. In several instances predators (mainly coyotes) were responsible for killing cattle. In one case, 6 cows and 6 calves were lost to coyotes on a suburban ranch of Fort Worth, Texas. This was an economic loss of $5148.00 to the rancher. Twenty-six coyotes were taken off of this ranch which was surrounded on two sides by urban communities.[3]

On an adjoining ranch, a similar situation occured with the loss of calves to predation by coyotes. At this site, 42 coyotes were taken off of the ranch.[4] Needless to say the ranchers involved in each incident were quite pleased with the results.

I have also worked complaints as have others at urban/suburban Air Force bases, airports, and other such areas. During these occasions, coyotes were traveling on the runways and creating a hazard for the aircraft or they were causing other physical damage to the properties. Control procedures had to be undertaken where possible to try and alleviate the damage. At some facilities this type of complaint occurs yearly.

Requests for assistance with these types of problems are continually being received and are increasing in frequency across the state. I am sure that similar scenarios could be given by other states as well.

OTHER ANIMAL DAMAGE

Beaver (Castor canadensis) have also found their way into the urban and suburban environment as well. Requests for assistance in urban areas are being received continually and once again are on the increase. In some urban areas as many as 2 to 3 calls per week are received regarding urban beaver damage.[5]

Complaints involving urban beaver damage include damage to trees and shrubs, the building of dams on creeks and waterways, the plugging up of drainage culverts, and other types of damage to private property. Beaver burrowing activity in water impoundments both public and private, is another common complaint from many urban areas.

Another increasing problem from within these areas is the incidence of human giardial infection caused by the transmission of the Giardia (Giardia lamblia) parasite by positively infected beaver (Beach 1985). A beaver can shed millions of infectious cysts in a single scat which is generally deposited in the water system in which the beaver inhabits.

The presence of bats in urban areas tends to create much anxiety particularly in the Central and South Texas region. Although bats are the second highest carrier of rabies in the state, most actual bat damage is slight and usually results from bats in a roosting situation.

Birds continually cause problems in most urban/suburban areas because of their roosting, feeding, and/or nesting habits. Bird droppings are also a problem when they accumulate in large proportions. Many different species of birds are involved in these damage or nuisance situations.

Recently, even exotic species of birds have involved themselves with the urban scene. Birds such as Cattle Egrets (Bulbuleus ibis) and Little Blue Herons (Egretta caerulea) have established heronries in urban areas of southern states (Telfair 1983). Complaints are also received regarding such species as Mississippi Kites (Ictinia mississippiensis) (Peterson 1985) and Monk Parakeets (Myiopsitta monachus) due to problems caused from their respective nesting activities.

Other types of animals have begun to inundate our cities as well. Not only do many people keep exotic pets (ie: lions, tigers, wolves, snakes, etc.) that escape periodically, native "exotic" wildlife are beginning to show up in these areas. Reptiles such as the Meditteranean Gecko (Hemidactylus turcicus turcicus) have caused problems. This lizard likes habitat around human habitations as its home and recently has appeared in Dallas which has not been in the animal's normal range of occurence.[5]

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[3]Thomas, Thurman R. 1988. Personal communication. Texas Animal Damage Control Service. Gatesville, Texas.

[4]House, Dayton. 1987. Personal communication. Texas Animal Damage Control Service. Mullin, Texas.

[5]Sramek, Ricky. 1988. Personal communication. Texas Animal Damage Control Service. Dallas, Texas.

I have also received complaints regarding a nuisance situation involving Rough Earth Snakes (Virginia striatula) and Texas Blind Snakes (Leptotyphlops dulcis). Both of these snakes are small (4 to 8 inches) and brown-colored and may occur around human habitations and/or find their way inside buildings.

DISCUSSION

Each of the complaint situations that have been related all required some form of associated control activity to help solve the damage or nuisance problem. This control activity is largely dependent upon the particular species of animal involved and the complaint background and locale. In most cases, technical assistance or control methods instruction is the desired and the primary mode of operation. Many times there are extenuating circumstances which may prohibit specific direct control activities being conducted.

With environmental concerns still in full swing, more and more urban areas are being designated as wildlife and/or bird sanctuaries where little or nothing can be done to alleviate wildlife damage without special and most often hard-to-get authorization. Also, a continually increasing amount of urban and suburban communities are adopting more and more restrictive city legislation which may limit control techniques. This includes the banning of the use of steel-jawed traps from within city limit boundaries, usually including Conibear traps, and the curtailing of the use of certain pesticides and the use of firearms.

Most local city animal control agencies are not set up for handling wildlife damage problems or do not have the personnel with the technical expertise to consult with a complainant on wildlife damage and control. This is particularly true in the smaller urban communities where funds and personnel are limited.

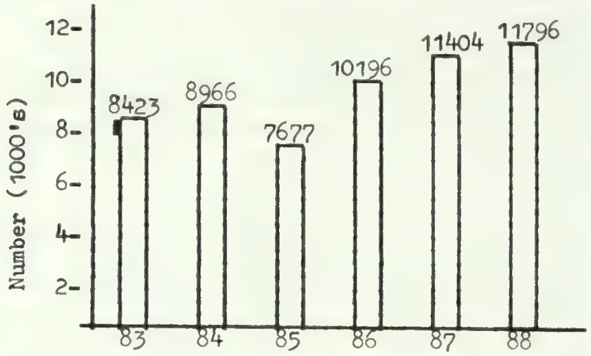
CONCLUSION

The wildlife damage complaints from within urban and suburban communities can be quite varied and may involve numerous wildlife species. There has been a continual increase in damage complaints and the associated technical assistance provided in Texas in the past few years (Table 1). Eighty-five to 90 percent of this technical assistance was provided by an urban wildlife damage control specialist.

By the year 2000, it has been estimated that 90 percent of the human population in this country will live in an urban area.[6] Consequently, there will be an increase in urban and suburban human/wildlife conflicts particularly of the kind described in this paper. Wildlife damage control specialists will be called upon in greater demand for assistance in solving these conflicts. He or she will need to address these problems in the most proficient and professional manner possible.

[6]Hawthorne, Donald W. 1987. Personal communication. Texas Animal Damage Control Service, USDA-APHIS-ADC. San Antonio, Texas.

Table 1. Technical assistance projects of Texas ADC Program, (fiscal years)



In order to effectively deal with these newer and more numerous complaints, it will take the combined efforts of civic, private, and state entities as well as the local wildlife damage control agency. These other entities need to be educated about wildlife damage and wildlife damage control in order that they too can at least provide the proper information to their public and/or provide the proper assistance to the control agent as needed.

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Urban Nuisance Wildlife Problems in Arizona[1]

Rebecca L. Wright[2] and Leonard L. Ordway

Abstract.-- Arizona has experienced an increase in urbanization of wildlife habitat, which has led to an urban nuisance wildlife problem. The Arizona Game and Fish Department is working to lessen the problem through public education, information packets and use of private pest control companies to remove wildlife for a fee.

INTRODUCTION

Wildlife has historically caused depredation and nuisance problems in rural areas nationwide. Typically, man controlled these problems through animal removal or exclusion. Over the last three decades, development of wildlife habitat and rural areas into metropolitan sites has increased, and population distribution has shifted from rural to urban. Nuisance wildlife problems have also shifted from agricultural damage to urban wildlife issues, ranging from a simple misunderstanding by citizens of wildlife habits to actual property damage by wildlife.

Arizona encompasses approximately 114,000 square miles. The state's population (3.5 million) increases each year by 3.5-4.5%, with most settling in urban areas (Arizona Department of Economic Security, 1988). Nuisance wildlife situations have also increased. According to Animal Damage Control's Arizona Annual Report (USDA, FY 1988), javelina (Tayassu tajacu) (fig. 1) caused almost $112,000 damage to crops, turf (golf courses), pets and gardens. Coyotes (Canis latrans) (fig. 2) caused $69,000 damage to livestock and crops. Beavers (Castor canadensis), black bears (Ursus americana), skunks and ground squirrels caused a total of $20,600 damage to private and commercial property.

Rather than being isolated or unrelated incidences, these nuisance wildlife situations are an expanding problem that the Arizona Game and Fish Department (AGFD) is striving to solve or lessen through education of the public, mail-out information packets to affected citizens, and licensing of private pest control companies enabling them to remove wildlife at a cost to the affected citizen.

URBAN NUISANCE WILDLIFE - CAUSES

The factors contributing to urban nuisance wildlife problems in Arizona are similar to factors seen nationwide. These four factors are: habitat transference, habitat destruction, human population expansion and wildlife population expansion/adaption.

Ownership or status of land in Arizona has changed as areas became more urbanized. First, land became private property or State and Federal lands; then the latter was either annexed by cities or developed into unincorporated towns becoming private property. This change in land ownership resulted in a change in habitat management and manipulation. Once annexed into cities or towns, property was developed into residential, commercial or industrial sites.

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[1] Paper presented at the Ninth Great Plains of Wildlife Damage Control Workshop, Fort Collins, Colorado, April 18-19, 1989.

[2] Rebecca L. Wright is Wildlife Manager (Scottsdale), Region VI, Arizona Game and Fish Department, Mesa, Arizona. Leonard L. Ordway is Game Specialist, Region VI, Arizona Game and Fish Department, Mesa, Arizona.

Figure 1.--Javelina (Tayassu tajacu) or collared peccary, frequently cause nuisance problems in metropolitan Phoenix and Tucson. These individuals were removed with tranquilizing dart gun.

Figure 2.--Coyotes (Canis latrans) are occasionally found in towns allowing horse properties or where washes and native vegetation remain.

Two modes of development have been used: 1) removal of native habitat, with evenly spaced residential or commercial communities, and 2) widely-spaced or clustered communities with corridors of native habitat left intact (this mode has become more popular as consumers and developers became more ecologically conscious). These two methods of development have created pockets of untouched or minimally impacted habitat surrounded by developed sites.

Newcomers to Arizona often relocate from more urbanized states. These new Arizonans often have had little experience with wildlife such as javelina, black bears, coyotes, skunks, racoons (Procyon lotor), mountain lions (Felis concolor), raptors, rattlesnakes and Gila Monsters (Heloderma suspectum). Long-time residents in once lightly populated towns who have not seen much wildlife in the past are seeing more wildlife as habitat is destroyed and these animals are forced to seek out other food and cover resources.

Wildlife species have adapted to new food, water, and cover resources in urbanized areas, resulting in an increase of frequency of wildlife sightings. Some species, such as the javelina, have increased in numbers and are also adapting to new habitats, such as ponderosa pine.

PROBLEMS CAUSED BY URBAN WILDLIFE

Despite development of wildlife habitat, often wildlife is not displaced. Instead, wildlife takes advantage of the new food, water, and cover resources presented to them. Landscaped yards, gardens, ornamental cactus, decorative ponds, drip irrigation systems, garbage cans, pet food, food set out for wildlife, and, occasionally, pets, replace traditional food and water resources. Sheds, garages, crawl spaces under house trailers, rafters, and attics are utilized as cover. Wildlife continue traveling on traditional movement corridors, despite development along these pathways.

The public frequently is uninformed about wildlife habits and legal status; many have unrealistic viewpoints on wildlife management. While many Arizonans enjoy seeing wildlife and, at times, encourage them by supplying food and water, many newcomers are surprised or frightened at the presence of javelina, coyotes, woodpeckers, etc. Just observing wildlife does not mean it is creating a nuisance. Yet, someone unfamiliar with a javelina is sure to have some concern.

When evaluating the situation with the affected citizen, Wildlife Managers try to assess what the problem is and how the citizen is contributing to the problem. Contributing factors include failure to remove wildlife attractants and failure to modify habitat (no fences, improper or inadequate fencing, failure to cover crawl spaces, etc.).

SOLUTIONS TO INDIVIDUAL CASES

AGFD has limited manpower and economic resources and cannot physically respond to all wildlife calls. Therefore, these calls are broken down into three categories: 1) injured or captive wildlife; 2) wildlife situations homeowners can alleviate themselves or by hiring a privately owned wildlife pest control company; and 3) live trapping or tranquilizing enclosed or dangerous wildlife. Wildlife Managers respond to any calls involving a threatened or endangered species, a big game mammal, or if the situation is life threatening or politically sensitive.

The first category ("come and get this thing") is cleared by phone instruction. The affected citizen is encouraged to bring the wildlife to the nearest AGFD office. If the citizen can't do this, then a volunteer for AGFD's Adobe Mountain Wildlife Center is sent to pick up the animal.

The second category ("we've got a problem and want you to remove it/solve it") is usually handled by phone instruction and mail-out information packets sent to the affected citizen. These packets contain information on removal of attractants, habitat modification, repelling individual animals, and removal of individual animals. In addition, information on Wildlife Service Permittees (WSP) is included in the packet. WSP are State Pest Control Board licensed pest control companies licensed by AGFD to handle nuisance wildlife (fig. 3). For a fee, a WSP will remove wildlife, develop plans to prevent wildlife damage or offer advice on how to prevent further damage. Currently, few companies work statewide; the majority work only in the Phoenix metropolitan area. As the number of nuisance wildlife calls increases in the metropolitan areas, these companies provide an invaluable service for AGFD.

The third category (removal of enclosed or dangerous wildlife) warrants response by AGFD personnel. Javelina, black bear and mountain lions have posed threats to humans or pets in metropolitan areas in recent years. These wildlife species have been known to become dependent upon food resources presented by humans; the animals then associate food with humans and, subsequently, lose their fear of humans. Occasionally, these animals become trapped on property and can't (or won't) leave. If all other attempts to exclude or deter the nuisance animal fail, then Wildlife Managers will attempt to remove the animal using live traps, tranquilizing dart guns or catch poles (fig. 4). Method utilized is determined by species involved, safety to officers and public, condition of animal, and number of animals involved.

Non-wildlife species such as pigeons and feral pets are handled by WSP or other agencies, such as USDA Animal Damage Control, County Rabies Control or the Humane Society.

LONG-TERM SOLUTIONS

Response to individual cases helps the immediate nuisance problem a property owner is experiencing, yet AGFD is working to prevent or

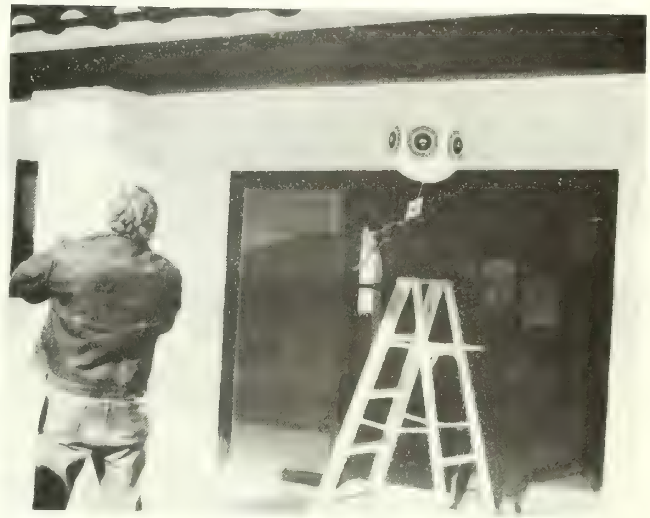

Figure 3.--Wildlife Service Permittees remove wildlife, devise plans, or offer advice on nuisance problems at a cost to the affected citizen.

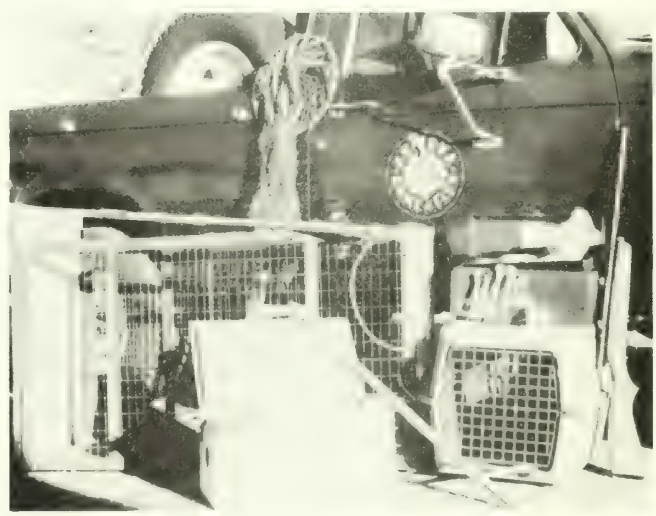

Figure 4.--Wildlife Managers use a variety of equipment for wildlife capture and removal (dart gun, net gun, catch pole, snake tongs, and live traps).

lessen future nuisance problems through education of the public, coordination of efforts of the six AGFD regions, and licensing and training of private companies to assist in wildlife removal. AGFD is designing brochures explaining life histories and habits of javelina, coyotes, small mamamals, birds, and reptiles that detail strategies for preventing problems from these species. These brochures will be available at AGFD offices and will be sent to Chamber of Commerce offices for inclusion in newcomers' information packets. AGFD is also designing slide shows and video tapes detailing nuisance wildlife problems; these will be made available to the public for talks and presentations. In addition, Wildlife Managers are working with community leaders, citizen groups, and city planning branches, outlining methods they can use to help educate their communities about urban wildlife. During the peak nuisance wildlife season, late fall to spring, AGFD collaborates with local newspapers and television stations reference articles and newsbriefs on urban wildlife problems.

AGFD is upgrading and expanding its Wildlife Service Permittee program. Improved yearly training sessions, revised report forms, and stricter reporting requirements allow AGFD to better supervise WSP actions. AGFD also expects to license pest control companies in metropolitan areas other than Phoenix; this will provide an invaluable service to the public and AGFD.

SUMMARY

Urban nuisance wildlife problems will continue to increase as wildlife habitat is developed and wildlife is forced to search out new food, water, and cover resources around metropolitan areas. Response to individual cases by Wildlife Managers will help alleviate immediate nuisance wildlife situations, but long-term solutions such as public education, use of private companies to assist in wildlife removal, and coordination with city planners and developers will help alleviate future urban nuisance wildlife problems.

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Urban Beaver Damage and Control in Dallas-Fort Worth, Texas[1]

Bob Willging[2] and Rick Sramek[3]

Abstract.--Beaver in metropolitan Dallas-Fort Worth, Texas cause considerable damage annually to trees, shrubs, and other property. USDA-APHIS-ADC reported 158 beaver complaints in the Dallas-Fort Worth area, 1984-1988, with damage totalling $60,395. Respondents to a beaver damage survey reported $170,900 in damage. Most incidents occurred at private homes on small creeks or lakes. Respondents used 11 different control methods, and spent $13,775 on control. Effective and consistent approaches to urban beaver damage control are needed.

INTRODUCTION

Beaver (Castor canadensis) populations have increased tremendously in the southeastern United States during the past 30 years, resulting in extensive damage to timber and agricultural resources primarily from flooding but also from direct cutting (Arner 1964, Toole and Krinard 1967, Godbie and Price 1975, Arner and DuBose 1978, Bullock and Arner 1985). Loven (1986) reported $391,153 in beaver damage to dikes and impoundments in Texas during a three year period.

In most southern states, beaver populations were probably at a low between 1890-1930 (Wesley 1978, Woodward 1983), but increased legal protection, low fur prices, and transplant efforts since then has caused beaver populations and distribution to greatly expand. Beaver were nearly extinct in Texas by 1900 (Wade 1986). Between 1939 and 1961 numerous beaver transplants by the Texas Parks and Wildlife Department, facilitated by strict protection and increased man-made water sources, led to the resurgence of the Texas beaver population, and damage complaints were common by the mid-1960's (Wade 1986). Presently there are few restrictions on taking beaver for damage control in Texas, but beaver populations remain high and are expanding.

Beaver damage to timber and agricultural resources has been documented extensively; however, beaver damage to urban and suburban property has received little attention. Beaver populations within the metropolitan area of Dallas-Fort Worth (DFW), Texas cause considerable damage annually to ornamental shrubs and trees, and other property. Beaver control in urban areas is frequently complicated by safety considerations, local regulations regarding the use of certain control methods, and widely varied public attitudes towards beaver control. The purpose of this study was to 1) Assess the extent of urban beaver damage in the DFW area, 2) Determine damage control and prevention methods used by residents experiencing beaver damage, and 3) Assess urban residents' attitudes towards beaver and control methods.

STUDY AREA

This study was conducted in Dallas and Tarrant Counties of northcentral Texas. The cities of Dallas and Fort Worth occupy nearly all of Dallas and Tarrant Counties respectively, and the DFW urban areas are referred to as one metropolitan area. The DFW area ranks 10th in population nationwide with over 3 million people, and covers 4,475 km^2. Both counties are highly urbanized and little land could be considered rural.

Surface water resources are abundant in the area due to its position in the Upper Trinity River Basin. The West Fork of the Trinity begins northwest of Fort Worth and joins the Clear Fork in Fort Worth and the Elm Fork in Dallas. There are 23 major reservoirs located in this basin, with 6 located in the DFW area. Additionally, hundreds of small creeks, ponds, and canals provide extensive riparian habitat for beaver.

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[1] Paper presented at the Ninth Great Plains Animal Damage Control Workshop. (Fort Collins, Col., April 17-20, 1989).

[2] Bob Willging is Assistant District Supervisor, USDA-APHIS-ADC, Fort Worth, Tex.

[3] Rick Sramek is a Wildlife Damage Control Specialist, Texas Animal Damage Control Service, Dallas, Tex.

METHODS

Management Information System

Data summaries for Dallas and Tarrant Counties from the USDA-APHIS-ADC Management Information System (MIS) between 1983-1988 were used to determine annual number of beaver complaints received by ADC, damage estimates, and types of damage. Texas ADC employees routinely complete a computer card reporting each damage complaint received, showing location, species, and type and value of damage. This information is entered in a central databank located at the state office in San Antonio. The MIS system became operational in 1983.

Survey

A 15 question survey with 3 sections was developed to obtain additional information about beaver damage situations. Surveys were sent to DFW residents who had been assisted by USDA-APHIS-ADC with beaver problems between 1984-1988. An attempt was made to send surveys to as many individuals as possible. However, lack of current addresses limited the number of surveys sent to 87. We were primarily interested in obtaining damage estimates, type of damage, control methods used, and attitudes towards beaver control.

RESULTS

Management Information System

Beaver damage from 158 incidents recorded on MIS from 1984-1988 totaled $60,395 (Table 1). Most damage was to ornamental plants and trees, which included typical nursery stock shade and fruit trees and shrubs, and to standing trees, which included wild, native trees. Other types of damage recorded included damage to lake or tank dams, and property damage such as to boat docks and wooden structures. Yearly totals of beaver complaints received by ADC have steadily increased from 12 in 1984 to 64 in 1988.

Survey

Sixty-three percent of the 87 surveys sent were returned. Most responses were from private homes (80%). The remaining 20% were from schools, churches, golf courses, and real estate developments. Damage occurred on small creeks or streams (55%), small ponds or lakes (40%), and reservoirs (2%).

Total beaver damage reported by respondents was $170,900 and ranged from $50 to $50,000 per complaint. Six exceedingly high damage estimates accounted for 67% of the total damage cost. Eliminating these high estimates left an average of $1,807 per incident. The six large damage estimates were reported by a university and private homeowners. Severe damage to pond dams and mature trees accounted for the higher estimates. No attempt was made to verify the accuracy of these estimates.

The most frequent type of damage reported was to ornamental plants and trees (55%). Other property damage reported included garden or fruit tree damage (11%), dike or dam damage (9%), and boat dock damage (1%). Other types of damage reported were flooding, erosion, and damage to wooden gates and fences. One respondent reported damage to a powerline caused by a beaver-felled tree. Some respondents regarded beaver as a nuisance or potential health hazard.

Eleven different damage control methods were used by respondents (Table 2). Most respondents used more than one method. Wrapping trees with hardware cloth or screen was used by 67% of respondents. Other methods frequently used were shooting (33%), conibear traps (18%), and exclusion fencing (18%). Respondents reported spending a total of $13,775 on control efforts. These costs ranged from buying a box of shotgun shells to spending $3,000 on labor to control beavers at a real estate development.

Respondents were asked to categorize each method used as successful (stopped damage), partially successful (some relief from damage), or not successful (no relief from damage). Protecting trees with hardware cloth or screen and shooting were consistently considered to be successful methods (Table 2). Most other methods were perceived as being only partially successful or not successful. Forty-five percent of respondents used some type of lethal control with 84% of them killing at least one beaver. Twenty percent reported killing over 5 beaver. The most used lethal method was shooting.

Sixty-seven percent of respondents were unaware that beavers existed in the DFW area until damage was experienced. Twenty percent had regarded beavers as endangered species before their damage experience. Most respondents (56%) were aware that nutria (Myocastor coypus) could be found in the area, and many people initially confused beaver damage with nutria damage. Fifty-five percent of respondents felt that assistance with beaver control was easily obtainable. Only 25% of respondents were opposed to lethal control, and of these, 50% would permit lethal control as a last alternative.

DISCUSSION

Damage

Damage estimates reported by survey respondents were several times higher per incident than that reported by ADC personnel. ADC figures are likely underestimates as they are usually based on one-time telephone consultations or brief inspections of the damage site. Damage reported by survey respondents varied widely and represent individual perceptions of damage severity. It is difficult for individuals to assign accurate and consistent values to urban beaver damage. For example, a mature shade tree has great sentimental and aesthetic value in addition to a high replacement cost. Realistic damage estimates for the DFW area probably lie between ADC estimates and landowner estimates. Both MIS data and survey results rep-

Table 1.—Beaver damage reported to USDA-APHIS-ADC Management Information System, Dallas-Fort Worth, 1984-1988.

		Damage Classification				
Year	n	Ornamental Plants	Standing Trees	Dams	Property	Totals
1988	64	$13,620	$1,575	$ 900	$ 600	$16,695
1987	44	$ 8,645	$4,575	$2,000	0	$15,220
1986	21	$10,960	$6,960	$ 500	0	$18,420
1985	17	$ 510	$5,363	0	$1,300	$ 7,175
1984	12	$ 1,835	$ 300	$ 750	0	$ 2,885
Totals	158	$35,570	$18,775	$4,150	$1,900	$60,395

Table 2.--Number of survey respondents who used control method(s), and degree of success perceived.

	Degree of Success				
Method	Successful	Partial Success	No Success	Totals	%[1]
Wrapped trees	15	20	2	37	67
Shooting	12	6	0	18	33
Conibear traps	4	2	4	10	18
Exclusion fencing	2	4	4	10	18
Repellents	0	4	5	9	16
Lights/Noise	0	3	5	8	15
Live trap	0	1	3	4	7
Do nothing	0	0	4	4	7
Leghold trap	0	0	3	3	5
Electric fence	1	0	1	2	4
Hired trapper	0	0	2	2	4
Snares	1	0	1	2	4

[1] Percent of respondents who used method at least once. Many respondents used more than one method.

resent only those landowners that contacted ADC for assistance. Many landowners experiencing damage attempt to solve the problem on their own or find assistance from other sources. It is evident that beaver damage in the DFW area is a real and significant problem.

Calls to ADC about beaver damage in the DFW area were rare prior to 1975, but have increased steadily since then. This increasing trend is continuing, due in part to an expansion of beaver numbers and range. Beaver, at first occurring in the major reservoirs and rivers, are now being found in small ponds, intermittent creeks, canals, and ditches. One beaver was found living in a drain pipe and was travelling through the storm sewer to feed on neighborhood trees. The increase in calls to ADC may also be due to an increase in suburban growth, and increased awareness of the existence of an ADC agency.

Control

Urban beaver damage control can be extremely frustrating for those affected. Few municipalities possess the expertise or motivation to deal with beaver damage, and local ordinances frequently restrict available control methods. When beaver damage begins it is often very noticeable and generally increases quickly, leaving the landowner feeling helpless. Survey respondents reported using

a variety of control methods, some representing desperate attempts to curb the damage. Surprisingly, 45% of respondents used lethal control methods, often shooting, despite local laws prohibiting the discharge of firearms within city limits. One landscaper felt that careful shooting was the only effective method available to him due to the safety risks of trapping and the infeasibility of wrapping hundreds of trees with wire fencing. We also were surprised that 75% of respondents were not opposed to lethal control methods, probably because the survey sample consisted only of those people familiar with beaver damage and the difficulties of control.

CONCLUSION

Beaver damage in the DFW area is an increasing problem and the adverse economic impact is likely to increase. However, there is no consistent, effective way in which urban residents can solve damage problems in a legal, safe, and biologically sound manner.

Many barriers to effective urban beaver control programs exist. Among these is a prevalent attitude among urban dwellers that urban beavers are somehow "special," which reflects a general lack of understanding about wildlife population dynamics and beaver biology. Experience has shown that a very few misinformed individuals, along with some negative publicity, can put an end to well intentioned and biologically sound beaver control efforts. Safety considerations and local regulations prohibiting trapping and shooting make effective beaver control difficult for the urban dweller.

The difficulties of urban beaver control may lead urban wildlife managers and animal control personnel to adopt a "do nothing" attitude or to suggest to the affected party that beavers should be enjoyed because they are beneficial and interesting. However, these approaches only make matters worse. While beavers may be beneficial in rural areas, there are few urban situations where benefits outweigh damage. Urban residents experiencing beaver damage will go to great lengths, lawful or unlawful, to control it.

It is clear that innovative, comprehensive approaches to urban beaver control, accompanied by a public education program, are greatly needed.

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Managing Urban Deer in Illinois: The Role of State Government[1, 2, 3]

James H. Witham and Jon M. Jones[4]

Abstract.--Decisions by communities to preserve open space within the Chicago Metropolitan Area have resulted in negative deer-human-habitat interactions. These conflicts can be addressed when communities develop consensus on management needs. In November 1988, the Illinois Department of Conservation initiated an urban deer management project to facilitate the needs of residents.

INTRODUCTION

White-tailed deer (Odocoileus virginianus) are abundant and widely distributed in the Chicago Metropolitan Area (CMA). Many urban residents develop an emotional bond with deer; some individuals relate philosophically to deer by passive coexistance or through a perception of mutual interdependence (Heintzelman 1988). Other residents appreciate deer as a natural component of a community, but also demand that coexistance is conditional. Conditional thresholds vary among individuals and are defined by the degree that a person and/or landowner tolerates economic loss (Caslick and Decker 1979, Porter 1983), reduced property aesthetics (Moen 1984, Conover and Kania 1988), increased health risk (Miller 1987, Lastavica et al. 1989), and the ecological impacts (Goldsmith 1982) that are often associated with wild free-ranging deer in urban environments (Decker and Connelly 1989).

Deer management activities in an urban environment are frequently focused on symptoms. In most circumstances, deer-vehicle accidents, browsing damage to native vegetation and ornamental plantings, and the transmittal of pathogens, are the predictable consequences of deer-human coexistance rather than being causal factors in themselves. These symptoms are common in the CMA (Witham and Jones 1987). Treating symptoms through use of site-specific damage abatement techniques (Craven 1984) is generally accepted by the public without significant issue. However, more comprehensive programs that involve population reduction and control require a broader understanding of conflict and a greater acceptance of responsibility among all participants.

In a region such as the CMA, where deer conflicts are abundant and repetitive, a state wildlife agency is well-advised to clearly define its level of involvement in urban deer management. Failure to formulate a definitive position increases opportunities for misunderstandings that can reflect negatively on state government and contribute to the divisiveness of issues.

In 1983, the Illinois Department of Conservation (IDC) contracted the Illinois Natural History Survey (INHS) to study deer-human-habitat relationships in northeastern Illinois. Research by INHS provided baseline biological data, identified and assessed the distribution of conflicts, evaluated alternative management strategies, and implemented experimental pilot studies that explored issues and established management precedence (Witham and Jones 1987). In November 1988, the IDC initiated a permanent Urban Deer Management Project that overlaps the final 14 months of the INHS research program. During this transition period, the IDC will define its role in urban deer management.

In this paper we describe factors that contribute to the recurrence of deer-human-habitat conflicts in the CMA, identify management needs, and suggest opportunities for IDC participation in urban deer management.

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[1] Paper presented at the Ninth Great Plaines Wildlife Damage Control Workshop, Marriott Hotel, Fort Collins, Colorado. April 17-20 1989.

[2] This study is a contribution of Federal Aid in Wildlife Restoration Project W-87-R, the Illinois Department of Conservation, the U.S. Fish and Wildlife Service, and the Illinois Natural History Survey, cooperating.

[3] Use of the word "urban" in the text denotes both urban and suburban environs.

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CAUSES OF DEER-HUMAN CONFLICTS IN CHICAGO

Urban environs are incomplete ecosystems lacking a wide complement of natural mechanisms that regulate deer populations. They are highly perturbed systems altered extensively by humans. In this setting, choices made by individuals, communities, and/or society, are the fundamental cause(s) of urban deer conflicts.

Insular Refuges: a Paradox of Preservation and Development

County forest preserves form the nucleus of primary deer habitat in northeastern Illinois. Since 1915, counties have acquired large sections of non-developed and rural landscape for the "purpose of protecting and preserving the flora, fauna, and scenic beauties...in their natural state and condition, for...the education, pleasure and recreation of the public (Wendling et al. 1981). In concept, forest preserve systems were designed as a network of interconnected refuges (Forest Preserve District of Cook County 1918). Some forest preserves have been developed for educational and recreational uses which include nature centers, zoological facilities, botanical gardens, and an extensive system of maintained picnic and recreation sites. Non-developed properties are a diverse mixture of native hardwood forests, reforestations, riparian systems, old-field succession, and leased agricultural fields.

In 1988, forest preserves totalled 394 km2 or 8.7% of Cook, DuPage, and Lake counties. The human population of 6.3 million in the 3-county CMA is projected to increase during the next decade (1 July 1986 census, U.S. Census Bureau, published in 1987). Private lands near many forest preserves, because of their aesthetic quality and/or higher economic value, have been extensively developed for residential, commercial, and industrial uses. Deer concentrate on preserves but readily cross heavily used highways seeking resources on these adjacent properties. Urban forest preserves will only become more insular over time. This will contribute to the escalation of deer-human conflicts in the CMA.

Demographic Responses of Deer on Preserves

Demographic responses of deer on quasi-insular preserves are similar to those expected of deer that are artificially protected within expansive exclosures. In the CMA, large predators are absent. Winter weather is harsh but within the normal limits of the northern range of the white-tail. Under such conditions, deer survival and productivity fluctuate predominately under the constraint and relaxation of weather variables and interannual variations in available nutrition. In rural settings temporal increases in deer abundance are more likely to be offset by dispersal and bv more liberalized harvest through recreational hunting. However, on relatively small, non-hunted, insular urban sanctuaries the negative consequences of increased deer abundance are accutely accentuated. High deer numbers on urban preserves will decline only through catastrophic dieoff triggered by severe weather or disease, or both; or a more gradual reduction through protracted malnutrition, accompanied by degradation of plant resources and a higher frequency of negative deer-human-habitat interactions. The latter best characterizes the conditions that exist on many CMA preserves.

Human Values and Management Efficacy

Moralistic, humanistic, and ecologistic characteristics are typical among urban publics (Kellert 1980). These prevailing values strongly affect the selection of methods used to control deer populations. In general, urban publics favor non-lethal techniques; however, non-lethal methods have demonstrated only limited effectiveness in reducing and controlling deer abundance. In contrast, lethal methods of deer population control are more effective but less acceptable to urban publics.

The inverse relationship between effectiveness and acceptablility of population control methods enhances polarization which is reinforced by different perceptions of the value of wildlife management literature. The wildlife professional is aware of the scope and value of deer management literature (see Wallmo 1981, Halls 1984) and uses this information to improve efficiency without reattempting techniques that have failed previously. Such acceptance is appropriate if it is refined by critical evaluation--a necessity because results presented in literature are at times ambiguous. Failure to provide this distinction perpetuates dogma and reflects poorly on the credibility of the wildlife profession. In contrast, those with opposing viewpoints may have limited knowledge and/or reject the value of wildlife management literature. The latter group frequently demands that all non-lethal alternatives are attempted before lethal control is considered. This syndrome of "reinventing the wheel" at each site is, at times, performed as a compromise to reduce socio-political conflict.

DEER MANAGEMENT NEEDS IN THE CMA

The resolution of urban deer conflicts requires cooperation between the state wildlife agency, the affected individual(s) or landowner(s), and those publics with special interest. None can resolve deer issues independently. A state wildlife agency regulates use of wildlife resources as defined by legislative mandated laws, whereas, land-use activities that are established by property owners are the principal determinants of wildlife abundance and population quality (Smith and Coggin 1984). Interested citizens can profoundly influence management decisions through socio-political processes since deer, and often times deer habitat, are resources held in public trust.

The IDC has no direct control over land-use decisions in the CMA; therefore, landowners must assume a direct participatory role in urban deer management. State wildlife regulations set the boundaries from which options can be selected; however, commissioners and officials of local governments are ultimately responsible for making specific decisions. Inherent in this responsibility is the need to balance human values against the limitations of management options. The role of state government in this process is informational. Landowners must have unbiased information on deer biology, ecology, and deer management alternatives with which to develop the expertise necessary to design, implement, and evaluate site-specific deer management programs.

URBAN DEER MANAGEMENT IN THE CMA

Program Goals

- o To acquire state-of-the-art expertise on urban wildlife management and local deer ecology for the purposes of management decisions and public education.
- o To facilitate cooperative management programs by providing information and training.
- o To increase awareness of urban deer ecology and to promote broader understanding of the consequences of an urban environment shared with wildlife.

Recommendations for State Involvement

The primary responsibilities of the IDC are to regulate wildlife use and to provide technical expertise. In urban deer management, the IDC must clearly distinguish between technical expertise and value judgement; questions of human values cannot be resolved technically and must be reconciled on a local level (Creighton 1984). In this context, the IDC should facilitate the needs of landowners who experience deer-related conflicts, interact responsively with publics that express special interest, but not arbitrate nor advocate values.

The IDC has approached urban deer issues proactively by establishing the deer specialist position in the CMA. A wealth of technical information exists on deer management strategies and methods to abate damage, but there is no universal panacea that will eliminate deer-human conflicts (Matschke et al. 1984). Control methods often produce ambiguous results. The role the IDC must take is to present this information accurately, and to the best extent possible, predict the consequences of specific decision alternatives. It remains the choice of the landowner whether or not to use the expertise provided by the state.

The urban deer specialist must be able to train landowners, or their representatives, in procedures for handling deer, controlling populations, and abating damage. Some landowners will prefer to contract this work to an outside source; there are many "deer experts" in the CMA. Under these circumstances the IDC must define minimum standards that will qualify an individual or organization to perform deer management services. The qualifying criteria should include possession of a specified level of liability insurance, technical expertise, and a demonstrated ability to use this expertise humanely and with maximum consideration for human safety.

Existing IDC policies and regulations on deer management may need to be adapted for application to urban settings. In some cases, new regulations will have to be developed since urban deer management differs substantially from traditional deer management practices in Illinois. For example, during the first six months of the Urban Deer Management Project the IDC established regulations on the translocation and free-release of deer, requirements for handling deer during live-capture, and modified procedures for the charitable donation of venison from animals killed in population reduction programs.

Applications submitted by landowners for deer depredations permits should include a proposal with a problem statement, program objectives, assessment of damage (if assessment is not quantified then the proposal should include quantitative procedures that will be implemented in the future), proposed methods, and an evaluation process that will measure achievement of success. This will encourage landowners to more closely monitor floral and faunal resources that may be negatively affected by deer. Furthermore, these minimal requirements force the landowner to articulate the exact nature of the conflict and how they expect the conflict to be resolved. In doing so, the landowner must address specifics rather than use superfulous terminology such as "overpopulation", "overbrowsing" or "carrying capacity" (Macnab 1985).

We expect the IDC Urban Deer Project to function as the central repository for data collected by local agencies. This will help standardize the collection of data and will promote exchange of information among landowners that are managing deer on their properties.

DISCUSSION

Currently in the United States there is a general movement from representative government to a participatory democracy. Increased public participation in decision processes is viewed more as a right than as a privilege (Creighton 1984). Urban deer issues provide a forum where this shift in attitude is readily apparent and perhaps, accentuated.

If communities choose to preserve open space and yet promote development, to perturb landscapes in ways that impair or eliminate forms of natural regulation of wildlife populations, to request abatement of deer-related damage but place limitations on the acceptability of techniques, then the communities must also accept a more active role in the management process. The IDC initiated the urban deer management project to help communities resolve deer-human conflicts. Success will depend on the ability of the communities to define their site-specific deer management needs and to select management responses that will effectively meet these needs.

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Controlling Raccoon Damage in Urban Areas[1]

David G. Riley[2]

Abstract: Raccoons have become a serious problem in many urban and suburban areas. Damage to homes and buildings as well as the spread of diseases to pets are constant problems when high raccoon populations occur. Various control methods can be implemented with positive results.

INTRODUCTION

In recent years, problems associated with raccoons in urban areas have become serious and very costly. This is due primarily to trends in real estate development and the human expansion into once rural areas. The idea of blending homes and office buildings into the natural surroundings is pleasant to the eye, but it can be an open invitation to the opportunistic raccoon.

Problems caused by raccoons can range from being a simple nuisance in the backyard to extreme structural damage to buildings, including holes in roofs and ceilings and damage to air conditioning systems and electrical wiring. Total monetary value of damage to buildings and other property in Texas for 1987 was $100,901.00. This figure represents only the damage reported to our agency. (Annual Report, 1987)

Another problem linked to raccoons is the spread of diseases to pets. Recently a study was conducted by Texas A&M University and the Austin area Health Department to test for leptospirosis in urban raccoons. Raccoons were collected in Austin, Texas by the Texas Animal Damage Control Service. The findings indicated that 61% of the raccoons tested positive for leptospirosis (Hudson, 1987). Dogs and cats are not vaccinated against this particular strain of the disease; therefore exposure to pets could increase the incidence of leptospirosis in people and pets.

Rabies is another disease that can be spread by raccoons. The national Centers for Disease Control received 1,311 cases of raccoon rabies in 1987. Of these, 1,298 (99%) were reported from the mid-Atlantic and southeaster states; areas of extreme urban development (CDC Summaries, 1988).

PROBLEM CIRCUMSTANCES

In most instances reports of raccoon damage are received from homeowners and businesses that are located within two or three blocks from a stream or green belt area. These natural corridors provide travel lanes by which raccoons are permitted to move throughout a city. Water, food, and shelter are available, depending on the amount of vegetation present. Usually there is not sufficient food or shelter for the local population of raccoons and during dry seasons, water can be in short supply. This lack of food, water, and or shelter, all essential elements, are the reasons why raccoons intrude upon people in urban areas.

DESCRIPTION OF RACCOON COMPLAINTS AND SOLUTIONS

The Texas Animal Damage Control Service provides assistance for various urban wildlife problems. The following are the most common complaints associated with raccoons.

1. Raccoons seen in the neighborhood: Many people do not realize that wildlife is abundant in urban areas, provided there is suitable habitat. In most instances this problem can be solved by providing the individual with information on urban raccoons.

2. Pet food, water, and garbage consumed by raccoons: Pet food left outside after dark and improperly stored garbage will attract raccoons to a home. Water bowls left out over night, uncovered hot tubs, and swimming pools are all easy to reach sources of water for raccoons.

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[1] Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop [Colorado State University, Fort Collins, April 17-20, 1989].

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With the exception of swimming pools, all of the above mentioned attractants can be stored properly with a little effort and discipline by the property owner.

3. Raccoons in attics and chimneys: This is the most common complaint received. Serious roof and interior damage can occur when raccoons are living in an attic. Exclusion, if feasible, should be implemented as soon as the problem is discovered. A permanent physical barrier between the ground and roof must be created. Raccoons usually gain access to a structure by way of a tree trunk or limb that is within two or three feet of the roof. To determine if a tree is being used, the trunk should be wrapped with a material that will show claw marks. Plastic trash bags, newspaper, or aluminum foil are all readily available and give good results. If a tree is being used by a raccoon, the trunk can be wrapped with a band of metal sheeting. The band should be 2½ feet wide and the bottom of the metal should be placed at least 2½ feet from the ground. Once in place the raccoons are able to reach the ground, but cannot climb back up the tree. Pruning of limbs used by raccoons may be necessary.

Many times raccoons will climb up the corner of a building. If this is the case, a metal sheet at least 3 feet square should be tacked around the corner. After exclusion of raccoons is complete permanent roof repairs can be made. Chimneys if uncovered, should be secured with heavy wire screening and fastened with masonry screws.

If exclusion is not successful or economical, trapping will need to be implemented.

DIRECT CONTROL

While exclusion or removal of the attractant (food, water, and shelter) is the best approach in dealing with raccoons, many people assume that trapping is the first and best choice. It is my opinion that trapping alone is a short term solution. The probability of raccoons reinfesting a building within a few months is very high. If exclusion and trapping are used very good results can be expected.

Raccoons are not difficult to catch in traps. In urban areas, the cage-type live trap should always be used. Single door traps are more effective for larger animals. If a trap with two doors is to be used, close the rear door. Bait should be placed behind the treadle well to the back of the trap. In selecting a bait, it is not necessary to use high odor fish products. This will attract house cats and possibly raccons other than those causing the damage. Peanut butter on bread or fruit and vanilla extract on bread are effective baits.

Once a raccoon has been trapped, it must be destroyed or relocated. Many people think the animal should be placed "back in the country where it came from". The fact is urban raccoons spend their entire lives in an urban area. Raccoons that are relocated into unfamiliar surroundings are stressed, disoriented, and have never searched for food or shelter in a rural area. The spread of disease to the rural raccoon population is very possible. Many of the relocated raccoons do not live very long after release. In North Carolina, 300 raccoons were tagged and released at a cost of $50.00 per animal; of these relocated raccoons only 16% (48) survived (Boyer & Brown, 1988). Tranquilizing followed by euthanasia is a more humane solution than allowing the raccoon to suffer from stress and starvation.

CONCLUSION

Urban raccoons and the problems they cause can be found in any city whenever food, water, and shelter are available. Wildlife damage control agencies can provide the public with information to increase their awareness of this and other wildlife related conflicts. This will enable people to better understand and deal with these problems as they arise.

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Relocation of City Raccoons[1]

Richard C. Rosatte and Charles D. MacInnes[2]

Abstract.--Twenty-four city raccoons were radio-collared and relocated 25-45 km north of the original capture site in Toronto, Ontario. Following release, extensive exploratory movements were noted with distances of 2-7 km being traversed per night. Home ranges for adult males ($\bar{x}$ = 39 km^2) and females ($\bar{x}$ = 72 km^2) far exceeded juvenile ranges and areas utilized by raccoons in an urban setting. None of the raccoons returned to the original point of capture and mortality of the relocated raccoons approached 50% during the first 3 months following release.

INTRODUCTION

Raccoons (*Procyon lotor*) are considered a pest in many city areas of southern Ontario (Rosatte 1986). Damage to lawns, gardens, residential roofs, chimneys and structures such as sheds and garages are commonly reported. There is also the potential for transmission of infectious diseases from raccoons to humans as well as to other animals (Wright 1977; Jacobson et al. 1982; Isaza and Courtney 1988).

Annually, more than 2000 "problem raccoons" are handled by the local Humane Society and animal control departments in the city of Toronto alone (Rosatte unpubl.). The dilemma is just what to do with those animals. Should they be euthanized, translocated to another locality, or should an investigation be initiated to establish methods to reduce human/raccoon interaction such as the design of predator-proof garbage containers. In many cases, the problem animals in Toronto are live-trapped, transported, and released in other areas. However, no follow-up has ever been carried out to determine the fate of those animals or establish that they did not return to the original capture site.

In 1986, the Ontario Ministry of Natural Resources in cooperation with the Ontario Humane Society initiated a research project to determine the fate of "city raccoons" translocated to either rural areas or a town. The major objectives of the study were:

(a) to determine the humaneness of relocating "problem raccoons" to unfamiliar areas;

(b) to estimate the survival rate of relocated raccoons;

(c) to observe the extent of exploratory movements by relocated animals;

(d) to predict the potential for infectious disease transmission from relocated raccoons to humans, domestic animals and wildlife;

(e) to determine whether translocated raccoons would return to the original capture site.

The following is a summary of the project results.

MATERIALS AND METHODS

Twenty-four raccoons (13 juveniles, 11 adults) were live-trapped (Tomahawk #106 - sardines as bait) in an urban area of Metropolitan Toronto between August 4 and October 1, 1986. The animals were immobilized with a mixture of ketamine hydrochloride and xylazine hydrochloride (10:1 ratio, 30 mg/kg ketamine), ear tagged for identification, weighed, measured and fitted with an adjustable radio-collar (Lotek Engineering, Aurora, Ontario - 151.309-151.467 MHz). They were also vaccinated against rabies with an intramuscular injection of Imrab inactivated rabies vaccine (Mérieux) and administered 0.5-1.0 ml of tetracycline to combat infection. Collared raccoons were then transported between 25 and 45 km north

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[1]Presented at the Great Plains Wildlife Damage Control Conference, Fort Collins, Colorado, April 17-20, 1989

[2]Richard C. Rosatte is a research scientist and C. D. MacInnes is supervisor, Wildlife Research Section, with the Ontario Ministry of Natural Resources, P.O. Box 5000, Maple, ON, Canada L6A 1S9.

of Metro Toronto and released in a rural setting or in close proximity to a town (fig. 1). Groups of 3-5 animals were released at weekly intervals between August 7 and October 1. Attempts were made to locate the collared animals 5 times/week until winter denning began in December. Animals with neck circumferences less than 24 cm were recaptured periodically and collars adjusted to accommodate growth. Collars were removed at the end of the study. Signals from the transmitters were monitored using a Trackfinder TFR-1000 receiver and a truck-mounted 3-element Yagi antenna. Grid locations were tabulated to the nearest 100 metres using triangulation of compass bearings and entered on a PDT-RT11 computer for data analysis. Home range was calculated using the Minimum Area method with a RADTRAC program designed by Queen's University (Voigt and Tinline 1980). Home range or area utilized by the collared raccoons was determined for the initial exploratory movement period and also immediately following that time until winter denning. The exploratory movement period was assumed to be complete when nightly movements were < 1 km. Calculated home range is also a minimum estimate

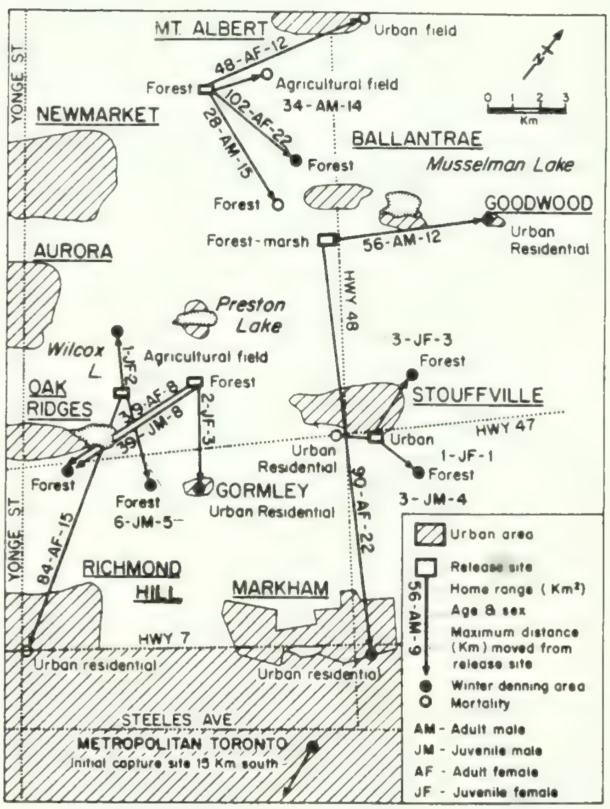

Figure 1. Release site and winter denning area of relocated urban raccoons.

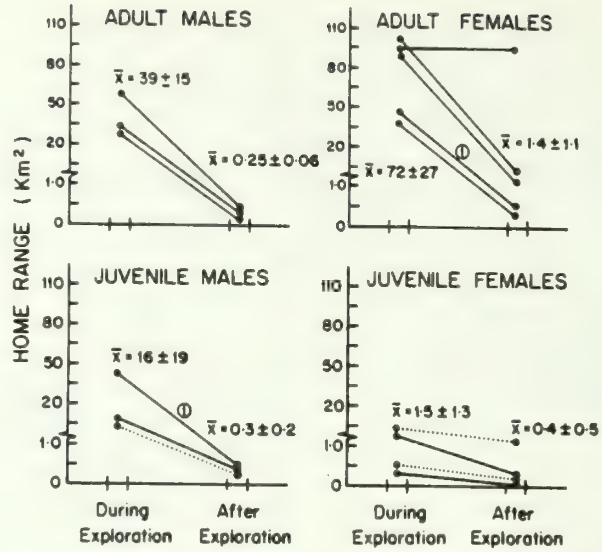

Figure 2. Home range of relocated raccoons during and after the exploratory movement period. (1) - adult female and juvenile male travelled and denned together. •.......• town release site raccoon

as locations were taken during the day when the animals were resting. No doubt a greater area would have been covered while they were active during the evening. For lack of a better term in defining the area utilized during the exploratory period, "home range" will be used in the text. Differences in home range and dispersal per age/sex class were tested using a 2-sample *t*-test (Zar 1974). Directional bias during dispersal was tested using critical values of r for a circular distribution derived from Rayleigh's Z values (Zar 1974). Significance was set at $p < 0.05$.

RESULTS

Sufficient data were gathered on 15 of the 24 collared raccoons for movement and home range analysis ($\bar{x}$ = 39 different fixes/animal). Those animals were monitored a mean period of 75.2 days (35-71, non consecutive) using 581 locations.

On the average, the collared raccoons explored for 27.7 days (range 9-47) before settling into a well-defined home range. Exploratory movements were generally between 2-7 km/night, while post exploratory movements were less than 1 km/night.

Home range of relocated raccoons

The home range or area utilized while exploring after release was greater for adult raccoons than juveniles ($p < 0.001$). However, after exploratory movements had ceased, we could find no differences in home range between age/sex classes ($p < 0.5$) (fig. 2). Adult home ranges were greater while exploring than after settling down ($p < 0.002$); however, we could find no differences in juvenile home ranges during and after the exploratory period ($p < 0.5$) (fig. 2).

Home ranges of raccoons transplanted to the town were smaller than those released in rural settings during the exploratory period ($p < 0.05$) (figs. 2, 3). However, we could find no difference after the exploratory period had ceased ($p < 0.5$) (figs. 2, 3).

Movements by relocated raccoons

Maximum straight line distance across the perimeter of the home range was greater for adults than juveniles ($p < 0.001$) (fig. 4). As well, the perimeter distance was greater for raccoons released in rural habitats than those released in the town ($p < 0.05$) (fig. 4).

The maximum distance moved from the release site and the distance raccoons settled from the release site was greater for adults than juveniles ($p < 0.001$) and greater for rural releases than the town releases ($p < 0.05$) (fig. 4). However, we could find no differences between age/sex classes, town or rural releases for distances between the original urban capture site and the area where the relocated raccoons settled down ($p < 0.1$) (fig. 4).

Directional movement bias

The mean angle of dispersal for all raccoons from the release site to the winter denning area was 148°, a S.S.E. directional drift. However, the drift was not biased to any specific direction ($p > 0.05$, $r = 0.330$) (fig. 5). The mean angle of drift following release for age/sex cohorts was: adult males - 99°, adult females - 194°, juvenile males - 229°, and juvenile females - 78° (fig. 5). Directional drift for the different cohorts was not biased to any specific compass direction ($p > 0.05$, $r = 0.269$-0.834).

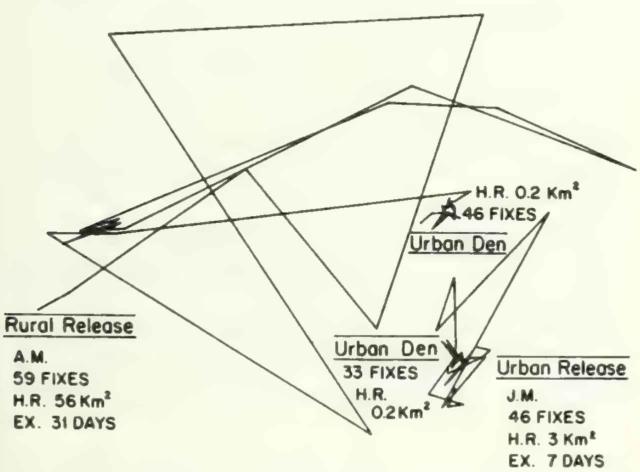

Figure 3. Home range of a rural and a town release site raccoon during and following the exploratory movement period.
H.R. = home range; A.M. = adult male;
J.M. = juvenile male; E.X. = exploratory period. Urban Release = town release

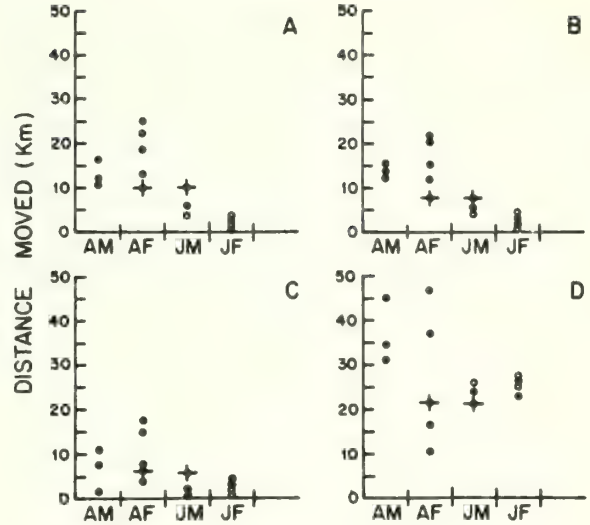

Figure 4. Distances moved by relocated raccoons following release.
A = maximum distance across home range perimeter
B = maximum distance moved from release site
C = distance settled from release site
D = distance settled from original capture site
o = town release site raccoon
• = rural release site raccoon
+ = juvenile male and adult female travelled together
A.M. = adult male A.F. = adult female
J.M. = juvenile male J.F. = juvenile female

Mortalities

Of the 24 relocated raccoons, 50% (12/24) succumbed within 3 months of release. Sources of mortality included shooting (5), road-kills (4), dogs (2) and poison (1). Three additional animals were possible mortalities as they could not be located despite live-trapping efforts, aerial and ground searches covering a 4500 km² area. However, we could find no difference in survival for animals released in the town (3/5) versus rural areas (10/19) ($p > 0.95$).

The physical condition of some individuals was very poor when recaptured in the fall. One adult and two juveniles actually lost weight during the period when they should be storing fat for the winter denning period. In fact, October-November weights of 3 juveniles were 1-3 kg (30-50%) below the mean fall weight of urban juvenile raccoons from the same capture site during a previous study (Rosatte et al. 1987) (fig. 6).

Post exploration locations

Following the exploratory period, 60% (9/15) of the raccoons settled a mean distance of 0.3 km (range 0-1) from a town. The remaining 40% (6/15) settled in forested rural areas an average of 3.0 km (2.1-4.3) from a town. None of those animals were ever located in a town. However, of the animals settling in or in close proximity to towns, 45% of their locations during the tracking period were in towns, mainly residential areas. For the whole tracking period, the 15 raccoons were located in mature deciduous forest 40% of the time, in residential areas 26% and in agricultural fields (mainly standing corn) 34% of the time. They settled into a combination of different habitats including urban residential, forest, agricultural field and urban field (fig. 1). Winter denning sites within those habitats included trees, open chimneys, abandoned barns and sheds.

DISCUSSION

Relocation of raccoons in North America is not a recent wildlife management practice. Since the early 1950's raccoons were trapped and relocated throughout different localities of South Carolina (Frampton and Webb 1974). As well, thousands have been transported from south Florida to Kentucky and Virginia for hunting purposes (Wright 1977; Jenkins and Winkler 1987). In Ontario, as raccoon populations are quite high, most relocations are due to human/animal conflicts and are termed nuisance relocations. During this project, we attempted to examine the fate of city raccoons relocated either to rural areas or a town. The foremost finding was the exceptional exploratory movement period undertaken by most of the radio-collared animals following release. Nightly forays of 2-7 km straight-line distance was common. Those movements were many times greater than annual movements made by radio-collared raccoons from the same initial capture site in Toronto ($\bar{x}$ = 0.8 km)(Rosatte et al. 1987). As well, home ranges during the exploratory period were exceptional when compared to those of urban raccoons in other cities. Annual ranges of 0.05 - 0.8 km² were common for raccoons in Washington, D.C., Cincinnati and New Brunswick, New Jersey (Cauley and Schinner 1973; Hoffmann and Gottschang 1977; Sherfy and Chapman 1980; Slade 1985). Mean annual home ranges for raccoons in the same initial capture site in Toronto were 0.42 km² (Rosatte et al. 1987).

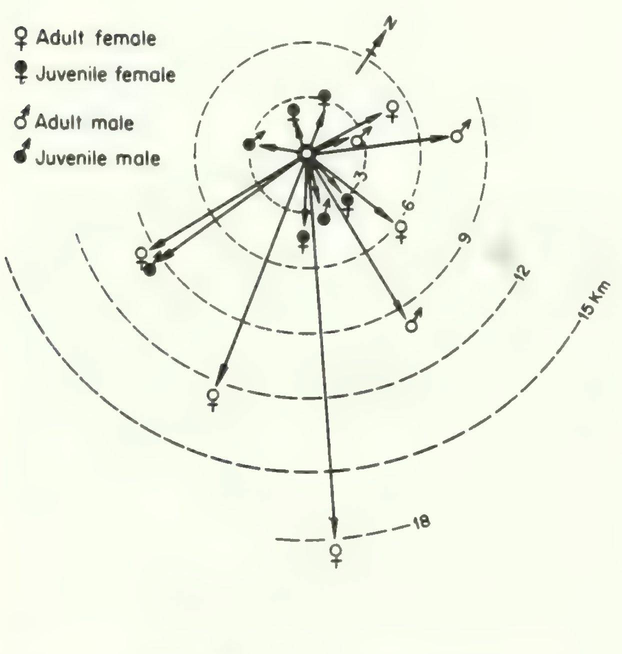

Figure 5. Directional drift by relocated raccoons following release.

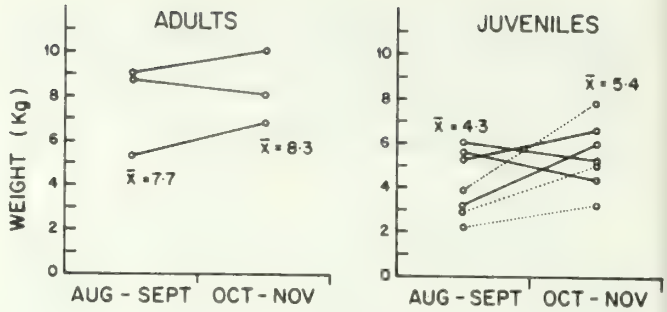

Figure 6. Weight gain/loss of relocated raccoons at the time of release and upon recapture. o……o town release site raccoon

The exceptional movements and extensive areas utilized by the relocated raccoons were possibly a result of disorientation through introduction to an unfamiliar environment. That hypothesis is supported by the fact that raccoons released at rural sites moved much greater distances than those released in a town. Once the animals became adjusted to their new habitat, home ranges compared well to raccoons in urban areas.

Disorientation is further supported in that none of the raccoons returned to the original capture site and there was no directional bias in movement following release. That suggests that raccoons do not possess any homing tendencies. Other researchers have also suggested that raccoons have no preference for direction or homing instinct when relocated (Frampton and Webb 1974).

The major concern with large exploratory movements by animals following relocation is the potential for the transmission of infectious diseases. A major epizootic of raccoon rabies in the mid-Atlantic U.S. during the 1980's was attributed to the translocation of raccoons from southern Florida to Virginia (Jenkins and Winkler 1987). As well, in Ontario during the late 1970's, an outbreak of rabies in skunks (*Mephitis mephitis*) was traced to the transplanting of nuisance animals from Mississauga

to Malton, both suburbs of Metropolitan Toronto (D. H. Johnston unpublished). The potential problem with relocation of wildlife is that the animal may be incubating an infectious disease while not exhibiting any clinical symptoms. The authors found a high percentage (55-60) of raccoons in Metro Toronto were serum positive for antibodies against canine distemper and feline panleukopenia. Raccoons have also been diagnosed with rabies, pseudorabies, *Baylisascaris procyonis*, canine parvovirus, canine distemper and canine adenovirus (Jacobson et al. 1982; Cranfield et al. 1984; Thawley and Wright 1982; Rabinowitz and Potgieter 1984; Dubey 1982; Rosatte 1988).

The humaneness of relocating urban raccoons must also be questioned. Mortality within the first 3 months of release was at least 50% and may have been as high as 75% due to the poor condition of some juveniles entering the winter denning period. Annual mortality in a sample (12) of radio-collared raccoons in Metro Toronto was less than 20% (Rosatte et al. 1987). Would it be more humane to euthanize the problem animals at the time of initial capture, or subject them to disorientation, starvation and mortality by dogs, automobiles, poison and shooting?

Another potential problem of relocating urban raccoons is the transfer of the problem from one locality to another. Most farmers in our area of relocation were exceptionally negative with respect to moving raccoons onto their farmland. Their major objections were due to past experiences with crop and building damage due to raccoons, as well as feces in grain storage bins and concern over the potential for disease transmission to their domestic stock. In our case, relocation of problem raccoons only resulted in shifting the human/wildlife interaction from the city to the country.

Solutions

The large number of human/raccoon conflicts in Metropolitan Toronto are due to high population densities of raccoons in some habitat types (Rosatte et al. 1987). Solutions to the conflict could include lowering the population density of raccoons in the problem area. That could be accomplished by:

a. the use of reproductive inhibitors or chemical sterilants in baits to render adult and juvenile female raccoons infertile (Howard 1967; Johnston et al. 1988; Kirkpatrick and Turner Jr. 1985);

b. the surgical sterilization of adult male raccoons following live-capture (Bojrab 1986);

c. euthanize problem raccoons following capture.

Probably the most effective method of alleviating the problem of nuisance raccoons is by exclusion. Many problems could be avoided simply by screening off chimneys and sealing all access to garages, sheds and barns. Predator-proof electric fences can be erected around gardens or an even cheaper method is to employ a watch-dog. If the only solution is to transplant, then if at all possible the animals should be vaccinated with a licensed vaccine to avoid the transmission of infectious diseases.

In conclusion, we do not recommend relocation of urban raccoons to solve nuisance problems as the potential for disease transmission due to large exploratory movements is high. As well, the humaneness of the technique has to be questioned due to high mortality rates and severe weight loss in juveniles.

ACKNOWLEDGEMENTS

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Colorado's Big Game Damage Program: 1979 to Present[1]

Andre C. Duvall[2]

Abstract.--Colorado's big game damage program, enacted in 1979, provides monetary claims for big game damage, prevention materials, and technical advice. Fences, crops, harvested crops, pasture, livestock, and personal property are protected. The average yearly cost for the program has been approximately one million dollars.

HISTORICAL OVERVIEW

The Colorado Division of Wildlife has always paid game damage of some sort. Prior to 1978-79, the Division was liable for damage to hay by deer and elk, and for bear and lion damage to livestock and personal property. Game damage payments totalled $300,000 prior to 1978.

With the extremely severe winter of 1978-79, the deer and elk herds were in serious trouble due to lack of natural forage. Despite a winter-feeding effort, many animals starved and were lost in the heavy snows. That winter the deer and elk caused excessively heavy damage to orchards and stacked hay. The Colorado Cattleman's Association had game damage legislation introduced into the Colorado House of Representatives to alleviate further game damage problems.

LEGISLATION

Colorado House Bill #1235 became law in March 1979 and outlined the legal responsibilities of the Colorado Division of Wildlife for big game damage. These responsibilities included: damage caused by deer, elk, antelope, moose, bear and mountain lion, bighorn sheep, and mountain goat.

Types of damages covered are: fences, crops, harvested crops, pasture and forage, orchards, and real or personal property. In 1981 additional legislation was passed in House Bill #1398. This made the Division also responsible for damage to nurseries. All these statutes were collected into Statute 33, Article 3: Damage by Wildlife (Colorado 1977).

PURPOSE STATEMENT

The Wildlife Commission created regulations to implement the new big game damage law. The Division defined the purpose of its game damage program as follows: "These regulations provide for the handling of big game damage claims, and are intended to provide the basis for compensation to claimants for losses suffered through the movements and feeding habits of big game" (Grieb 1979).

RESPONSIBILITY

The Division is responsible for deer, elk, antelope, moose, bighorn sheep, and mountain goat damage to the following: significant damage to fences on private property in amounts of $100 or more per incident; significant damage to livestock forage which exceeds 10% of the grazing capacity, seasonally deferred grazing land, crops under cultivation, harvested crops, hay meadows, artificially seeded rangelands, pasture meadows, orchards, and nurseries. Damage to ornamentals and home shrubbery is not covered by this law.

Damage to real or personal property by black bear and mountain lion is also the Division's responsibility. Real or personal property is usually taken to mean: livestock, poultry, bee hives, rabbits, buildings, fences, etc. It does not cover campers, automobiles, or camping gear and equipment (Colorado Division of Wildlife 1979).

CLAIM PROCEDURE AND LEGAL RESPONSIBILITY

In order for a claim for big game damage to be approved by the Wildlife Commission, the following procedure must be adhered to:

1. A 10-day notification must be sent to the Division that specifies: dates; numbers and species of big game; type of damage; estimate of damage extent; and location. If damage is recurring, a notification must be sent every 10 days. The Division must investigate the alleged damage within 10 days of the receipt of

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[1]Paper presented at the 9th Great Plains Wildlife Damage Control Workshop. (Fort Collins, Colo., April 17-20, 1989).

[2]Andre' C. Duvall is Terrestrial Wildlife Biologist, Colorado Division of Wildlife, Northeast Region, Fort Collins, Colorado.

notification and provide claim papers if requested by the landowner.

2. An investigative report must be filled out and filed as part of the claim by the investigating officer of the Division at the time of initial notification of the damage.

3. Proof of Loss forms must be returned to the Division by the landowner within 90 days of ending notification of damage. Proof of Loss forms also include forms specific to the damage claimed so it can be correctly documented.

4. Upon receiving the claim, Division of Wildlife representatives must meet with the landowner-claimant within 30 days to try to reach a mutual agreement for the settlement.

5. Claim papers in their entirety must be sent to the appropriate Regional Manager and then to Denver headquarters for payment.

6. Any approved claim for less than $2,500 is paid out of the game damage funds appropriated for that purpose.

7. Any claim over $2,500 must be approved by the Wildlife Commission.

8. If any claim is denied, it must be reviewed by the Wildlife Commission. The claimant has the right of appeal within 30 days to the Wildlife Commission on denials.

9. If the claim is still denied by the Wildlife Commission, the claimant may enter the case before the local district court. The time allowed for this action is within 60 days of official receipt of claim denial (Colorado Division of Wildlife 1980).

10. If claimant cashes the damage payment check, he can no longer appeal the case to the courts.

BIG GAME DAMAGE OPERATIONS AND POLICIES

Predators.--When bear or mountain lion damage complaints are received, the damage is investigated as quickly as possibly so the evidence does not deteriorate to the point where the cause of death is difficult or impossible to ascertain.

Payment on all predator-damaged livestock, other than sheep, is made on the current market value of the animals. Sheep are compensated for on a sliding scale of value due to the unpredictability of the market. The Division has the right to receive the opinion of a licensed veterinarian to determine the cause of death in predator damage cases and often does so, particularly if the value exceeds $1,000.

Bear and mountain lion, killed during the commission of game damage, become the property of the state and must be turned over to the Division of Wildlife within 5 days. When the need arises, the Division has an established list of lion and/or bear hunters who are qualified to hunt the offending animals.

Ungulates.--There are three areas where damage done by ungulates has the severest impact in Colorado: hay stacks; crops under cultivation (usually alfalfa); and orchards.

With hay damage, the payment and investigation center on amounts such as bales, tons, or pounds of hay damaged. Payment is based on replacement value of the hay at the time of damage.

Claims for damage to crops under cultivation are among the most difficult to substantiate. Generally to prove a claim on growing crops, a count of the damage causing animals must be made every 5 days for as long as the damage is continuing. This count is substantiated by Division of Wildlife personnel and is the basis for the average number of big game animals on the claim. One method of evaluating such losses is to compare damaged to undamaged portions of the crop. Another is to clip, air dry, and weigh sample vegetation. A final method is to assign a forage basis, by poundage, to a particular species. This figure is then multiplied by the average number of big game present and the amount of time, in days, they foraged on the crop. The total is then the amount attributed to the game damage claim.

Orchard damage is computed on a percentage basis for each tree unless totally destroyed. Trees are listed by age, species, and production records to determine value.

In areas of severe game damage by ungulates, a damage hunt may be selected as a control measure. An established list of eligible hunters is maintained and may be called at any time of the year for a supervised, controlled damage hunt. A specific number of animals are taken and all are utilized by the hunters or donated to charitable organizations by the Division of Wildlife.

CLAIM DENIALS

There are conditions where game damage claims are denied. If the claim is false and is discovered to be so, claim payments are not made. If the claimant restricts access to private land or denies access to public land under his or her control, for the hunting of the species causing damage, the claim can be denied. Lastly, if the claimant charges over $25 per hunter per season, the claim may be denied under the game damage statute.

BIG GAME HISTORICAL LEVELS

The Division of Wildlife is obligated to determine historical levels of big game ungulates for use in the settlement of game damage claims. These levels are based on the 20-year population averages starting January 1, 1953 and ending January 1, 1973.

FINANCIAL CONSIDERATIONS

The costs of Colorado's big game damage program are paid entirely by big game hunting license revenue (game cash).

In fiscal year 1979-80, one and one-half million dollars were appropriated from game cash monies for the damage program. Approximately $300,000 was paid in claims, $350,000 for manpower and labor, and $850,000 was used to purchase damage prevention materials.

In the intervening decade from 1979 to 1989, the damage program has cost in range of $600,000 to $1,000,000 per year. Claims have averaged approximately $200,000 yearly, with the rest spent for prevention materials, supplemental feed, and labor costs.

DISCUSSION

Colorado's big game damage program has had some interesting consequences.

The Division has spent approximately $10,000,000 over the last decade, which could have been used in other wildlife related endeavors.

Hunting seasons have been influenced and herd objectives (actual numbers of big game animals) have been changed. In some cases, big game herds have been decreased due to damage situations and landowner insistence.

The concept of "wildlife ranching" has in part developed out of the big game damage program and associated concerns.

Large landholdings that previously allowed no access, are now open to reasonable numbers of hunters and recreationalists. This is due to damage claim payment approval being tied to reasonable access to attain harvest.

In some areas of severe damage, the Division has been able to lease or purchase real estate for the state's sportsmen.

Overall, relations have been improved with many ranchers, farmers, and other large landowners. Many now work more closely with the Division on wildlife management activities due to claim payments, damage control efforts, hunting and regulation strategies, and getting to know Division of Wildlife concerns and personnel,

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Colorado's Liability for Big Game Damage to Livestock Forage[1]

Len H. Carpenter[2]

Abstract.--The Colorado Division of Wildlife is liable for damage to livestock forage by big game animals under 2 categories. First is damage to livestock forage in hay meadows, pasture and artificially seeded rangelands. The second is damage to livestock forage on grazing land that is deferred for seasonal use. Calculation of damage is complex and involves consideration of several factors. Damage is based upon the difference between grazing capacity and amount of grazing actually realized by the claimant, provided that amount of damage could have been caused by the big game animals documented to have used the area. Factors such as numbers and kinds of big game animals, current wildlife population, historic wildlife population, animal month equivalents, dietary overlap, forage values, and proportion of time spent on the area by game animals in question must be considered. Approximately $50,000 has been paid to claimants for forage damage since 1978.

INTRODUCTION

The first legislation concerning big game damage in Colorado passed in 1931 when the state became liable for damage to haystacks. In 1969, liability for damage by big game animals was broadened to include loss of livestock, damage to fences, and growing crops. In 1979, orchard damages, losses of livestock forage on artificially seeded rangelands, and losses of forage on seasonally deferred pastures were included in Colorado's big game damage legislation.

The objective of this paper is to describe Colorado's liability for damage done to livestock forage on private lands. Provisions of the legislation and procedures for determining amount of damage and calculation of payment will be discussed. Problems with the process from the viewpoint of both the state and the claimant will also be highlighted.

DEFINITIONS AND PROVISIONS

Colorado Division of Wildlife Regulations Chapter 17, based on Colorado's Revised Statutes Title 33-3, covers damage caused by big game. There are 11 articles in this chapter. Articles IX and X pertain to damage to livestock forage. Article IX deals with damage to livestock forage in hay meadows, pasture and artificially seeded rangelands. Damage to livestock forage on grazing land which is deferred for seasonal use is covered in Article X. Article I presents general provisions which includes definitions important to the legislation. For purposes of this paper it is important to define certain terms.

> "Damage" means any change in the quality or quantity of any property which reduced its value. Damage shall include all costs necessary to restore property to its condition immediately prior to damage, to replace it with property of equal value or to compensate for restoration or replacement.
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> "Historic levels" means the average number of a species of big game that occurred on the property in question during the 20-year period of January 1, 1953 through December 31, 1972.
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> "Artificially seeded rangelands" means land on which grasses or legumes have been seeded, and have become established to the extent that 50 percent or more of the useable livestock forage production is from the seeded species and whose primary use is grazing by livestock.
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> "Grazing land" means land used primarily for production of native forage plants for livestock grazing as differentiated from lands where a crop is harvested.

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"Grazing land which is deferred for seasonal use" means grazing land that is designated for a postponement of grazing by livestock for a specific season(s) with the purpose of reserving forage available for grazing by livestock during a later season.

"AUM equivalents" means the equivalent number of months required for each big game species to equal 1 animal unit month (AUM). The equivalents are: 13.6 antelope months, 8.7 bighorn months, 9.9 deer months, 2.5 elk months, 1.4 moose months, and 10.3 mountain goat months.

Several additional provisions are pertinent to this legislation. No claim for big game damage will be approved where the claimant or other person who controls the land where damage occurred has unreasonably restricted hunting for the species causing damage. A damage claim will be denied when a fee in excess of $25.00 per season has been charged any person for big game hunting access onto or through any lands owned, leased or otherwise controlled by the claimant, or the landowner if the claimant is the lessee.

Any person who submits a claim for damage shall provide a certified statement that damage prevention materials provided by the Division, if any, were used in an effort to prevent or reduce the extent of damage and were not used for any other purpose. In addition, any person who submits a claim for damage shall provide a certified statement on his/her proof-of-loss form that the damages for which he/she is submitting a claim are, or are not, covered under an insurance policy and that he/she does not contemplate receiving insurance compensation for damages claimed.

DAMAGE TO LIVESTOCK FORAGE IN HAY MEADOWS, PASTURE, AND ARTIFICIALLY SEEDED RANGELANDS

Proof of Loss

At the time of the investigation or upon submission of the proof-of-loss form, the claimant shall be responsible to prove by a preponderance of evidence:

1. That the damage occurred and it was more than 10 percent in excess of normal historic wildlife use levels.

2. That damage occurred and that the claimant was unable to graze the damaged area at the rate which would normally be expected by the claimant for this area under similar growing conditions in the absence of big game grazing.

3. That damage was caused by big game and not adverse weather, insects, rodents, or some other cause.

4. That the claimant owns the land or leases it from a private owner.

5. That the meadow, pasture or artificially seeded range land was fenced and that the fence was adequate to exclude any livestock present on adjoining lands.

Documentation of Claim

Documentation by the claimant which is necessary to support a claim includes the following:

1. A statement of the actual beginning and ending dates that the area was grazed.

2. A statement of the numbers of livestock animal units grazed by species.

3. A proof-of-loss form prepared jointly by the claimant and a Division of Wildlife investigator after the livestock grazing period has been completed. Such form shall include an estimate of the amount of grazing which was still available, if any, at the time of investigation.

4. A statement of the number and kind of big game using the designated area including data from all of the claimant's counts made by date and time of day and a list of all known witnesses who participated in those counts which shall be made at least once during every five-day period. Numbers of big game shall be expressed in terms of the average number of animals present and shall include an estimate of the percentage of their daily food intake consumed or damage on the designated area.

5. A statement characterizing the nature of the growing season in one of three categories: favorable, normal, or unfavorable. A growing season shall be considered favorable if, on the average, more favorable conditions occur 1 year in 4 or less frequently. A growing season shall be considered unfavorable if, on the average, less favorable conditions occur 1 year in 4 or less frequently. Such statement shall include data on normal and current year dates of last killing frost and amount of rainfall by week from the nearest weather station, or by other records or evidence where such records are kept.

6. An estimate by a professional range conservationist or other similarly qualified person, acceptable to the Division and claimant, of the normal grazing capacity of the damaged area considering the actual growing conditions, range condition and type of livestock grazed. Such estimate shall include a detailed written description of the basis used to determine grazing capacity.

7. If the damaged area is a hay meadow, a certified statement of the date of last hay cutting.

8. A statement designating the historic average number(s) of big game, by species, present on the property in question.

Evaluation and Settlement

Amount of damage shall be the difference between the grazing capacity of the area and the amount of grazing actually realized by the claimant. Grazing capacity is determined by forage measurement procedures which meet U.S. Soil Conservation Service standards. Liability is limited to that proportion of the damage in excess of the historic big game use levels, and the State shall be liable for such damages only if they are more than 10 percent in excess of normal historic wildlife use levels. This proportion is obtained by subtracting the 1953 to 1973 average population from the current population for the species causing damage and dividing this difference by the current population. The following formula is used for these calculations:

$$\underset{\text{(whichever is less)}}{GC - GAR \text{ or } WNC \times WUM's} \quad X \quad \frac{WC - WH}{WC}$$

where:

GC = grazing capacity of the area in livestock AUM's available

GAR = grazing actually realized in livestock AUM's

WC = current wildlife population

WH = historic wildlife population

WNC = average number of wildlife actually counted

WUM's = wildlife unit months

$$\left(\frac{1}{\text{livestock AUM equivalent}}\right).$$

Value of grazing shall be the current market value at the time and place of the forage loss. Values computed for loss of dry standing forage shall be reduced by the amount which would have been required for purchase of necessary protein, and/or energy supplements if the forage had been used for grazing.

DAMAGE TO LIVESTOCK FORAGE ON GRAZING LAND THAT IS DEFERRED FOR SEASONAL USE

Notice of Intent to Defer Grazing

Any person designating all or part of his/her grazing land as "deferred for seasonal use" shall provide written notice to the Division no later than 30 days prior to the beginning date of intended deferral period. This notice must include a map and legal description of the grazing land which is to be deferred. A statement from a professional range conservationist stating the range site(s) included within the area to be designated and the range condition class(es) of the area is required. In addition, a signed statement by the owner or grazing lessee of the deferred lands is required which certifies that the area to be deferred is surrounded by a fence adequate to exclude livestock from adjacent lands. This statement must also provide the beginning and ending dates of the intended deferral period and the numbers of livestock animal units by species which are intended to be grazed.

Proof of Loss

At the time of the investigation or upon submission of the proof-of-loss form, the claimant, shall be responsible to prove by a preponderance of evidence:

1. That he/she met the requirements concerning notice of intent to defer grazing on the lands where the damage is alleged to have occurred.

2. That damage occurred and it was more than 10 percent in excess of normal historic use levels.

3. That livestock was unable to graze the area at the rate under similar growing conditions in the absence of big game grazing, and that the damage was caused by big game and not adverse weather, insects, rodents or some other cause.

4. That he/she owns the land or leases it from a private owner.

5. That the land was adequately fenced to exclude any livestock present on adjoining lands.

Documentation of Claim

Documentation by the claimant which is necessary to support a claim for damage to deferred grazing land shall include the following:

1. A statement of the actual beginning and ending dates that the area was grazed.

2. A statement of the numbers of livestock animal units grazed by species.

3. A proof-of-loss form prepared jointly by the claimant and the Area Wildlife Manager or his/her designee after the grazing had been completed. Such form shall include an estimate of the amount of grazing which was still available, if any, at the time of investigation.

4. A statement of the number and kind of big game using the designated area including data

from all counts made by date and time of day and a list of all known witnesses who participated in these counts.

5. A statement describing the quality of the growing season as favorable, normal or unfavorable.

6. A statement designating the historic average number(s) of big game, by species, present on the property in question.

Evaluation And Settlement

Amount of damage shall be the difference between grazing capacity of the area and amount of grazing actually realized by the claimant. All definitions, procedures, and calculations presented on meadow and artificially seeded rangelands apply except for the following modification. If the deferred grazing land contains a substantial amount of herbage other than grasses and legumes, the AUM equivalents must be adjusted for the amount of herbage that was consumed by big game that was not livestock forage. This adjustment is made by dividing the appropriate AUM equivalent by the proportion of dietary overlap for the species of wildlife and livestock involved. This proportion (Table 1), shall be used unless some other figure can be shown to reflect more accurately the situation in question. The adjusted AUM value represents the average total amount of forage that could have been eaten by big game.

Table 1.--Dietary overlap values used to adjust AUM equivalents for the amount of herbage consumed by wildlife which is not livestock forage.

Big game species	Cow	Sheep
Elk	0.91	0.96
Deer	0.50	0.80
Antelope	0.80	0.80

PAYMENT HISTORY

During the 10 years that Colorado has been liable for damage to livestock forage by big game there have been 73 claims paid totaling $50,290 (Table 2). The greatest number of payments (21) occurred in 1983-84 which was one of the most severe winters on record. Over the 10 years there have been an average of about 7 claims per year with each claim averaging nearly $689. Over 90 percent of the 73 claims have been in the category of meadows and artificially seeded rangelands.

There have been additional claims filed which for various reasons were not approved. Throughout the evaluation process, an arbitrator may be used if the Division and the claimant cannot agree to the values in question. This is especially true for the determination of the historic levels of a big game species. After the investigation is completed and the Division fails to approve a claim, the claimant has the right to appear before the Wildlife Commission and argue his/her case. The Wildlife Commission then approves or disapproves the disputed claim based on the evidence presented. If approved by the Commission, the claim is paid.

Table 2.--Number of claims and money paid for damage done to livestock forage for years 1978-79 to 1987-88.

Year	Claims	Total Payments ($)
1978-79	1	1,270
1979-80	1	256
1980-81	2	1,184
1981-82	6	1,183
1982-83	5	3,378
1983-84	21	13,423
1984-85	14	8,998
1985-86	9	11,894
1986-87	6	2,354
1987-88	8	6,350
Total	73	50,290

DISCUSSION

Obviously the process of documenting, evaluating, and paying a claim is complex. This has proven to be a major frustration for both the Division and the claimant. In many cases it costs more to document and investigate a claim than the claim is worth. The considerable paper work required is a major hurdle for the private landowner and results in many potential claimants not following through. Even though it could be argued that this is good from the viewpoint of the Division, it is actually a liability because working relations between the Division and the landowner suffer when this happens.

There need to be improvements in the process. One possible solution might be forage leasing arrangements worked out between the landowner and the Division before damage occurred. The money could come from a fund that is limited in amount (i.e. some percentage of big game license fees), ear-marked, and set aside for this purpose. Landowners would sign up in advance on a first-come first-served basis and reach agreement with the Division on the forage value per AUM equivalent. The unknown in this arrangement would be number of big game animals (animal unit month equivalents) on the property in question. This would be determined during winter and spring months when damage was occurring. This agreement could be strengthened by including penalties or forfeiture of payment if hunting was unreasonably restricted by the landowner during regular hunting seasons.

Some people suggest that the State should not be liable for forage. However, if it is agreed that forage is a value either as livestock food or as big game food, and if that forage is removed from private land by public animals, then it can be argued that this is a loss to the private landowner and should be compensated. The question becomes one of what is the damage? Is it weight loss by the livestock grazing the forage which has been reduced by the big game animals? Is it a loss in reproductive capability of the livestock foraging due to reduction in forage? Is it a delayed birthing period as a result of the lowered nutritional level of the livestock? Is it reduced range condition as a result of too many herbivores grazing that range? Or is it some combination of all of the above?

These questions need answers. Unfortunately, finding answers will not be easy. The Colorado Division of Wildlife is currently conducting research in Northwestern Colorado on effects of different densities of elk during winter and early spring, on spring livestock forage. Measurements are being made on cow and calf weight performances, livestock birth dates, and range condition. Additional controlled research efforts like this are needed. It would be much easier to determine liability and design equitable compensation if the true damage were known.

Habitat Manipulations to Prevent Elk Damage to Private Rangelands[1]

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Abstract.--Habitat manipulations were initiated on the Wick Brothers big Game Winter range in southern Wyoming to alter traditional movement patterns of Rocky Mountain Elk (Cervus elaphus nelsonii). Manipulations included spraying with 2-4-D and follow-up fertilization of the same plot in successive years with ammonium nitrate at the rate of 40 lbs. (18 kg.) free nitrogen per acre. Burning hay meadows and upland sagebrush sites and salting were used in combination with the other treatments. Elk distribution shifted to the treated plots in response to the increased quality and quantity of the grass production on these areas. Spring distribution of elk shifted to Department lands and away from private lands. This shift in spring elk distribution should augment efforts to enhance calving habitat and develop a migration corridor south of the unit through silvicultural treatments on adjacent National Forest land.

INTRODUCTION

The impact of elk (Cervus elaphus nelsonii) grazing on native rangelands has received increased interest in recent years from members of the Wyoming Agricultural Industry. Historic elk use was tolerated until the depressed economy of the agri-industry brought increased need of efficiency in the livestock operation. By the late 1970's and early 1980's, several landowners and ranch managers questioned the use of private rangelands by elk, in what they felt was direct competition with their domestic cattle operation. As a result, an increased number of damage claims was received by the Department pertaining to wildlife use of private lands. Those claims are legally covered under Title 23 Article 9 of Wyoming Game and Fish Law.

The State of Wyoming Game and Fish Department pays damage as mandated by state statute 23-1-901 which states; "The Department shall consider the claim upon a description of the livestock damaged, the damaged land, growing cultivated crops, stored crops, improvements and extraordinary damage to grass." In several cases ranchers claimed damage to native private rangelands as a result of early season grazing by elk, under "Extraordinary Damage to grass." By definition in the regulation, extraordinary use means, "the consumption or use of noncultivated grass plants in excess of the consumption or use which normally occurred during the two (2) years immediately preceding the time covered by the claim." (Wyoming Game and Fish Law, Revised, 1988).

In response to these damage claims, department personnel work load was shifted to accommodate the need to document elk distribution and numbers on private land. Pre-claim data is a necessary prerequisite for determining baseline or normal use and "Extraordinary use" or use in excess of the baseline use. Documentation became labor intensive and other alternatives were researched to simplify the process. Historical use by elk of private lands was documented and use calculated in the form of Elk Unit Months (EUMS). Conversion to the universal Animal Unit Months (AUMS) was made and the claimant reimbursed for that use.

Efforts to alter this historic use pattern were initiated to reduce the number of elk using private land and reduce the cost of managing the elk that winter on the Wick Unit.

Our research focused on one elk herd that traditionally utilized private native rangelands in the spring where claims of alleged damage had occurred. The problem centered around the spring migration of elk off of winter range owned by the Department and private native

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rangelands adjacent to the unit. A list of options was formulated to reduce or eliminate conflicts.

A thorough review of the literature on migration provided insight into the behavior of these elk. The literature suggested that elk migrations are traditional (Murie, 1951; Brazda, 1953; Craighead, et al., 1972; Knight, 1970) and are learned behavior (Anderson, 1958; Murie, 1951). Recent research addressed elk spring migration patterns in the terms of habitat; habitat requirements and habitat accessibility during movements from the winter range to spring range (Adams, 1982; Compton, 1975; Skovlin, 1982). Researchers also indicated ungulate use could be altered through salting, fertilizing and spraying. Dalke (1965) reported salting has a limited effect on spring elk distribution, yet research also suggested that movements of elk were related to use of natural salt licks (Knight, 1970). Christensen (1969) reported that elk distribution could be changed by spraying sagebrush (Artemesia sp.) and Skovlin et al. (1983) suggested that elk distribution could be altered with vegetative manipulations including fertilizing.

STUDY AREA AND METHODS

A study was initiated in 1981 to address four objectives; 1) document travel routes of radio collared elk off the Wick Unit onto summer range; 2) determine the response of elk to vegetative manipulations on the Unit and on adjacent National Forest lands; 3) identify important elk use areas on Unit and adjacent National Forest lands as spring transitional range which could be enhanced; 4) inventory the vegetative and physical characteristics of habitats used by elk in the spring.

The Wick Brothers Big Game Winter Range study area is about halfway between Laramie and Rawlins, in south central Wyoming. The unit is located 6 miles (9.65 km) southeast of the town of Elk Mountain, Wyoming, on the northern edge of the Snowy Range. Elevation of the study area ranges from 7,263 feet (2,214 m) to 8,907 feet (2,715 m). The topography is dominated by high rolling hills and benches. Major watersheds include Mule Creek, Wagonhound Creek and Foote Creek, tributaries of the Medicine Bow River. Precipitation averages 15.6 inches (39.73 cm) and moisture occurs generally as snow and early spring rains. During the winter, wind keeps the upland sites snow free and available to elk. Snow deposition is generally in the draws and stream bottoms as a result of snow drifting. The area is mapped to range sites using the Soil Conservation Service Technical Guide (1978) and has been summarized by Pinchak (1983). Range sites include wetland, subirrigated, grazeable woodlands, loamy sites, very shallow, shallow loamy and coarse uplands. The sites on private lands classed as very shallow, shallow loamy, and coarse uplands appear to be the most vulnerable to spring grazing in the areas where cattle and elk use overlap.

Field work was initiated in 1982 in the pretreatment phase of the project. Adult elk fitted with radio collars have been monitored since 1982. Radio collars have been placed on 19 cows and 1 bull during the course of this project. Elk were collared primarily to determine migration routes, the response of these elk to any shift in migration routes, and the use of the vegetation treatment areas on the Unit and on National Forest land.

In an attempt to hold elk on the Unit longer in the spring, series of manipulations were planned. The use of salting was first initiated in 1982, burning and spraying in 1983-1985, and fertilization with ammonium nitrate was applied in the fall of 1985. The use of fertilizer was repeated again in 1986 on plots treated previously by spraying 2-4-D on sagebrush. Spraying was generally directed at Big Sagebrush (Artemisia tridenta), 3-tipped Sagebrush (Artemesia tripartita) and Black Sagebrush (Artemesia nova). Mat forming forbs, as well as the sagebrush, were removed, releasing the grass communities.

RESULTS AND FINDINGS

Transects were established following treatments in 1983. A standard utilization cage and end of the year production transect utilizing a circular hoop of 9.6 sq. ft. (.8918 sq. m.) was read in 1984 (Stroud and Pers. Comm.). The 1984 results of the 2-4-D spray program showed a dramatic increase in grass and forb production (Table 1) when followed up with fertilization of ammonium nitrate. The elk responded to the increased forage quality and quantity and regularly were observed on vegetative treatments.

It appears that both fertilizing and spraying are useful in attracting elk. However, the benefits from fertilization appears to be more short lived. Fertilization acted as an attractant for two successive years. Spraying and the resulting change in the plant community, appears to prolong elk use over time.

Table 1. Results from the plot sprayed with 2-4-D and fertilized with ammonium nitrate. (Stroud, 1985).

Production	Treated 1983	Control 1983
Grasses	676.7	235.0
*Forbs	246.1	285.1
Shrubs	94.3	260.8

*Forb production appears to decline on treated area. However, reduction in mat formers increased production of other forbs.

In addition to the vegetative treatments a program of salting was initiated in 1982 to attract and hold elk. This program showed limited success. However, it appears that elk did use salt heavily through all phases of the project. Shifts in elk distribution were documented to areas near established salt stations.

The use of salt and the use of the treated areas by elk appeared to be greatest in late March and April which coincides with the period of damage on adjacent private lands. In the areas treated by fertilization and herbicide, elk use increased 3 fold over pre-treatment levels, 50.8 EUMS compared to 130.0 EUMS. Shifts in elk home ranges between years was also documented, favoring the treated areas.

Concurrent with habitat improvements on the Wick Unit, the Forest Service and Wyoming Game and Fish personnel designed a timber sale on adjacent National Forest land to improve spring elk habitat. Clear cuts were designed to create a mosaic of openings, aspen patches, and conifer stands to provide better habitat for elk calving and spring forage. A number of the clearcuts were designed to blow free of snow to provide winter forage and access to the upper Wagonhound drainage in early spring. This silvicultural treatment was proposed to augment efforts on the winter range to hold elk on public land in spring and attract elk away from traditional calving areas and spring migration routes determined from monitoring telemetered elk. The timber sale was complete in 1987. The slash should be treated and the clearcuts should be seeded with grasses in 1989. The response of the elk will be determined by monitoring radio collared cow elk over the next two years.

DISCUSSION AND SUMMARY

Both telemetered elk and noncollared elk responded to increases in vegetative production on areas treated by fertilization and herbicide. Shifts in spring use patterns of marked elk towards the treated areas and reduced use of private rangelands were noted. The treatment and post treatment data clearly supports other research which indicates the usefulness of vegetative manipulations to alter ungulate distribution (Christensen, 1969; Dalke, 1965; Skovlin et al., 1983). In the case of the Wick Unit, the manipulations established a use pattern that could enhance efforts to establish a migration corridor on public land.

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Characteristics of Deer Damage to Experimental Orchards in Ohio[1]

Kerry M. Mower,[2] Thomas W. Townsend,[3] and William J. Tyznik[4]

SUMMARY

We measured several variables of newly established apple trees (1) to compare growth differences between trees damaged by browsing deer (<u>Odocoileus</u> <u>hemionus</u>) and trees protected from deer, (2) to determine if seasonal browsing patterns existed, and (3) to determine if deer browsed selectively among Ohio's 3 most commonly planted apple cultivars. All testing was done at the 0.05 alpha level. Experimental trees were measured repeatedly from June 1986 through May 1988.

Trees were planted in experimental orchards planted at research farms representative of areas where apples are grown commercially. Each experimental orchard contained 20 trees each of 3 cultivars, red delicious, golden delicious, and red rome. Trees were planted randomly by cultivar pairs and one tree of each pair was enclosed in a welded wire cylinder 1.5 m high to exclude deer. Eight orchards were planted the first year; 5 additional orchards were planted the second year. At the beginning of the second year half of the tree pairs in the 8 original orchards were randomly selected and the exclosures switched from the control to the treatment tree. Trees were measured monthly the first year, and bimonthly the second year because the trees were much larger. Variables measured included branch length, number of leaves/branch, number of leaves/cm of branch length, and browsing frequency. Radial growth was determined by measuring trunk diameter at time of planting and each autumn thereafter.

Length of branches in all orchards but 3 were significantly reduced by browsing deer and browsed trees in all but 2 orchards had significantly reduced numbers of leaves. Browsed branches were observed in all but 1 orchard. The reduction in branch length ranged from 0% in the single undamaged orchard to 98% in one of the most serely browsed orchards; reduction in number of leaves/branch had a similar range from 0% to 85%.

Significant seasonal effects were found in branch length, number of leaves/branch, and browsing frequency between browsed and control trees. Two seasonal patterns existed among significantly browsed orchards. Browsing was concentrated either in early summer or autumn. Orchards with greatest branch and leaf reductions sustained significantly more browsing in early summer than any other season. Browsing in these orchards began as soon as trees began to grow and decreased only when trees failed to initiate new growth, became dormant, or died. Orchards with lower levels of browsing were damaged in late autumn and winter. Deer began to browse these orchards at the time leaves dropped from trees in adjacent wooded areas. Leaves persisted on apple trees longer than in surrounding forest trees. Sporadic browsing continued into winter in such orchards.

No evidence was found that deer selectively feed on any of the 3 cultivars tested. Browsing was severe enough to cause higher mortality among treated trees in 6 orchards ($p < 0.01$). Four orchards were moderately browsed; mortality rates between browsed and unbrowsed trees were not different but radial growth was reduced significantly among browsed trees. Three orchards were browsed lightly, neither mortality rate nor radial growth was significantly different between browsed and unbrowsed trees.

After 2 growing seasons, most foliage was beyond the reach of deer. Browsing damage is most critical to small and immature trees. Growth rate and tree vigor are affected by edaphic conditions, rootstock, and cultivar. Under conditions of rapid growth, apple trees can outgrow the detrimental effects of deer browsing and protection might only be needed the first 2-3 years.

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. Forth Collins, Colorado, April 17-20, 1989.

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Deer Damage to an Austrian Pine Tree Nursery in Wheatland, Wyoming[1]

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Abstract.--During the winter of 1987-1988 southeastern Wyoming experienced severe weather conditions. The agricultural land south and west of Wheatland, Wyoming became critical to the survival of both mule and white-tailed deer. A 120 acre commercial tree nursery was located in these farmlands at the foothills of the Laramie Mountain range. Approximately 150 deer moved into the nursery seeking both hiding and thermal cover. Shifting snow created large snow drifts throughout the area which inhibited the foraging patterns of the deer. The deer yarded up within the confines of the nursery and were forced to consume pine needles in an attempt to meet their daily energy requirements. This foraging by deer caused various degrees of damage to 4,564 Austrian pine trees. Evaluation techniques used to determine the extent of the damage in monetary terms were those developed by a tree and landscape appraising firm. The completion of the evaluation resulted in the largest single damage claim ever paid by the Wyoming Game and Fish Department for wildlife depredation.

INTRODUCTION

During late December (1987) and throughout January (1988), southeastern Wyoming experienced severe winter weather. Mule deer were driven down from their winter ranges in the foothills of the Laramie Mountain range by heavy snows, cold temperatures and strong winds, and were forced into the agricultural land south and west of Wheatland, Platte County, Wyoming. The extraordinarily high density of deer in this area created many depredation problems, most of which occurred to easily accessible and unprotected piles of field corn and stacked alfalfa hay. Centrally located within this agricultural area is a commercial tree nursery, operated by Wyoming Evergreens of Wheatland, WY. The nursery, at this time, was nine years old, 120 acres in size, and producing approximately 120,000 trees. Deciduous and coniferous trees were being grown, however, the majority of production was in coniferous trees such as Austrian pine (*Pinus nigra*), Ponderosa pine (*Pinus ponderosa*), Blue spruce (*Picea pungens*), Bristlecone pine (*Pinus aristata*), and Rocky Mountain juniper (*Juniperus scopulorum*). During the severe weather, the nursery provided excellent hiding and thermal cover for a large number of displaced deer. Although a livestock fence encompassed the nursery, it was not a barrier to deer movements.

DAMAGE INVESTIGATION

In early February, 1988, the Wyoming Game and Fish Department (WGFD) was informed by Wyoming Evergreens nursery manager that wintering deer had caused extreme damage to a large number of trees within the nursery. As winter progressed, shifting snow had created large drifts throughout the agricultural area. The deep snow inhibited foraging patterns and approximately 150 mule and white-tailed deer yarded up within the confines of the nursery. As the deer became stressed by the winter conditions, they browsed heavily on the nursery stock in an attempt to meet their daily energy requirements. Subsequent field investigation of the damage revealed that the majority of damage had occurred to the Austrian pine trees. Although several species of trees had sustained various degrees of damage, the Austrians were apparently the most palatable.

The Austrian pine is a native of central and southern Europe and Asia Minor. It is very adaptable to nearly any growing condition,

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Ft. Collins Marriott, Ft. Collins, Colorado, April 17-20, 1989].

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adaptable to nearly any growing condition, provided there is full sunlight. It's growth form is densely pyramidal, stiffly branched, and wide spreading. The fascicles of two needles are dark shiny green on yellow-brown twigs. Needles are recurved and range between 3 and 6 inches and are both unbendingly stiff and very sharply pointed. Winter buds have a pineapple-like silhouette and are very hairy. The rough bark is dark brown-gray and noticeably grooved (Hudak, 1980).

The most apparent damage to the trees was needle removal through browsing (fig. 1). Closer examination of the damaged trees revealed that many of the lateral branch buds had been selectively removed (fig. 2), and depending upon the height of the tree, terminal branch buds had also been browsed off. The actual amount of deneedling varied from slight to over 50% of an individual trees' needles. On many of the severely damaged trees needles had been eaten to within one-half inch of the branch. The majority of deer had moved out of the nursery due to improving weather when investigated by Department personnel, but 40-60 deer were still utilizing the nursery.

Figure 1. An Austrian Pine tree which sustained heavy deneedling to it's lower branches due to deer browsing.

To prevent further damage to the nursery, short-term scare tactics were employed. Zon guns were set up around the perimeter of the nursery and operated on a 24-hour basis. In addition, nursery personnel patrolled the area

Figure 2. An Austrian Pine tree showing lateral branch bud removal due to deer browsing.

during the night periodically shooting explosive cracker shells and whistle bombs provided by the WGFD.

DAMAGE EVALUATION

Wyoming Evergreens estimated there were 20,000 Austrian pines in the nursery. Of these, 12,000 were considered to be six to twelve feet tall and of harvestable size. The remainder of the Austrians were five feet tall or less in height. Although as previously stated, several species of trees sustained damage, Wyoming Evergreens was interested in recovering damages only to an estimated 4,564 Austrian pines.

Under current Wyoming statue (W.S. 23-1-901) the WGFD is responsible and may be held liable for damage caused by big or trophy game animals or game birds. In 1981, John Demaree and Tim Fagan, Damage Control Wardens (WGFD), organized a handbook of methods used to evaluate various types of wildlife damages. The handbook is used as a reference source for the majority of the damage claims submitted to the WGFD. However, there were no techniques described in the handbook for evaluating damage to nursery trees. Generally, damage to ornamental trees was just a matter of determining replacement costs.

In an attempt to locate previously used evaluation techniques, literature searches were conducted through the U.S. Fish and Wildlife Center in Maryland, and the Science Library at the University of Wyoming in Laramie, WY. Neither search resulted in locating workable evaluation techniques for our situation. Several western and mid-western State agencies

and Universities were contacted with virtually no success in identifying previously tested procedures.

On several occasions, WGFD personnel attempted to formulate workable evaluation techniques. At the same time, the nursery also continued to refine their estimates of the actual damage and unfortunately, agreement over the actual cost figures between Wyoming Evergreens and the WGFD could not be reached. Subsequently, Wyoming Evergreens suggested contacting a tree buyer from Denver, Colorado who had done business with the nursery in the past and who was, therefore, familiar with their operation. After visiting the nursery, the tree buyer felt that he was not qualified to assess the actual damages in monetary terms. The buyer recommended contacting Eyerly and Associates, Denver, Colorado, a consultant firm which provides landscape and tree appraising services. Shortly thereafter, the consultant firm was contacted by the WGFD, and the damage situation explained to them. It was learned through this contact that the firm had extensive nursery business background and served as a principal witness for the U.S. Justice Department in a court case in Arizona. After having reviewed the available information, the firm felt that the damage claim could possibly be assessed utilizing National Standards currently in use for appraising damages due to hail storms. The firm also agreed to evaluate the damages in monetary terms and to support their findings in a court of law if the need arose.

ASSESSING THE ACTUAL DAMAGE

The evaluation procedure began by determining the average size of the damaged trees and placing them into four categories. Category 1 trees ranged from 7 to 9 feet (averaged 8 feet), Category 2 trees ranged from 6 to 7 feet (averaged 6.5 feet), Category 3 trees ranged from 3 to 6 feet (averaged 4.5 feet), and Category 4 trees ranged from 2 to 4 feet (averaged 3 feet).

The next step was to identify the quantity of trees that sustained deer damage. Information on size and quantity was obtained from information submitted to the WGFD by Wyoming Evergreens. The consultants reviewed the information and after an on-site inspection of the nursery, concurred that the numbers provided were reasonable. Then utilizing Wyoming Evergreens' catalog of available nursery stock and 1988 price lists, and examining the current fair market value of Austrian pine sizes not listed by Wyoming Evergreens, a basic value/tree was assigned to each category. By multiplying the basic value/tree by the number of trees in that category, a total cost was determined for each category. Since the prices quoted in the catalog included the costs of digging, market preparation, and freight charges (within 200 miles), it was necessary to deduct this cost from the total cost. Digging costs were considered to be less for trees under six feet in height, therefore, two separate digging cost figures were used. The number of trees/category multiplied by the digging cost/tree gives the digging cost/category. Then by subtracting the total digging cost/category from the total cost/category, you obtain the initial value/category of the damaged trees.

There were two basic assumptions made that should be identified here. The first is that each of the damaged trees is considered a total loss to the nursery, therefore, damages will be assessed only one time. Wyoming Evergreens had proposed that because the damage was variable, some of the trees would take longer (years) to recover than others. Based on this, a restoration plan over a four year period was suggested. The plan would have required annual inspections with a payment applied each year based upon growth and recovery rates. However, the consultants felt that this type of plan would project too many variables, such as environmental conditions, degree of care, current market value, disease and other unknowns. The second assumption is that the initial value of the trees is the value of a tree that was in perfect growing condition prior to the deer damage. This condition is based upon a tree's annual growth rate, percent decadence, structural weakness, the presence of insects and/or disease, mechanical injury, survival conditions, and life expectancy. The condition of a tree is evaluated as a percentage along a scale from 0 to 100%. It was determined by the firm that the condition of the trees prior to the deer damage ranged from 30 to 60% and that a fudge factor of 5% should be added to provide a reasonable average of 65%.

Multiplying the initial value/category by the condition factor gives the total value of the trees in each category. Since the trees are considered a total loss to the nursery, there are removal and cleanup costs that need to be considered. As with the digging costs, the cost to remove and cleanup a damaged tree varies with the size of the tree. Once this cost/size of tree was determined, the removal and cleanup cost/tree was multiplied by the number of trees/category to determine the additional cost of the trees/category. The sum of the total value/category and the removal and cleanup cost/category equals the assessed damages due to deer depredation/category. Finally, the sum of the four category assessments equals the recommended damage claim payment (figure 3).

Figure 3. The calculations used in determining the recommended damage claim payment were:

C_i = a category of trees by average height
N_i = number of trees/category
BV = basic cash value of a tree given it's height
TC_i = total cost/category
dc = digging cost/tree given it's size
DC_i = digging cost/category
IV_i = initial value/category
CF = condition factor
TV_i = total value/category
rc = removal and cleanup cost/tree
RC_i = removal and cleanup cost/category
AD_i = assessed damages/category
RDCP = recommended damage claim payment

so, the calculations for each category are:

$$TC_i = BV_i \times N_i$$
$$DC_i = dc \times N_i$$
$$IV_i = TC_i - DC_i$$
$$TV_i = IV_i \times CF$$
$$RC_i = rc \times N_i$$
$$AD_i = TV_i + RC_i$$

then, the recommended damage claim payment is:

$$RDCP = AD_1 + AD_2 + \ldots$$

SUMMARY

The damages awarded to Wyoming Evergreens is to this date the largest amount of money ever paid by the WGFD for an individual deer depredation claim. We feel that the procedures followed by Eyerly and Associates to assess the damages were fair and reasonable. As part of the damage claim agreement, Wyoming Evergreens was informed that all of the 4,654 damaged trees had to be removed, and documentation of that action had to be provided before future damage claims would be considered. It was also suggested that a deer-proof fence be installed by Wyoming Evergreens to prevent deer movement into the nursery. The nursery has since erected an eight-foot deer-proof fence.

Prevention of damage situations is always the preferred course of action; however, this may not always be possible. It is important that States such as Wyoming which are financially liable for wildlife damage make available through publications and workshops those techniques and procedures for damage evaluation that are workable, tested, and acceptable. In addition, state wildlife agencies should promote and fund scientific research to develop improved evaluation techniques which are specific to unique wildlife damage situations.

LITERATURE CITED

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Experimental Applications of High-Tensile Wire and Other Fencing to Control Big Game Damage in Northwest Colorado[1]

A. Eugene Byrne[2]

Abstract.--Conventional fencing methods - V-mesh wire, square mesh wire and wood panels are compared to experimental methods - 15 wire high-tensile wire fences; electric high-tensile wire fences of three designs; baited electric fences; hog panel fences; plastic mesh fences and visqueen wrapped haystacks. Total cost of materials, cost per ft./yr. and comments concerning estimates of efficacy are discussed. The V-mesh wire, hog panel and plastic mesh fences all have a very high cost per ft. and cost per ft./yr. rating and should probably not be used. High-tensile and square mesh wire fences are effective and cheaper alternatives. Modern high-tensile wire electric fences can be an effective alternatives in some situations. Results from tests using visqueen wrapped haystacks and baited electric fences are encouraging and more experimentation is needed. Wood panels should only be used as an emergency game damage prevention method.

INTRODUCTION

The Colorado Division of Wildlife (CDOW) has statutory responsibility for big game damage to growing crops, orchards, nurseries, fences, harvested crops and livestock forage. Most years the CDOW spends over $1,000,000 per year for game damage prevention materials and claims. From 1979 - 1988, CDOW personnel in Northwest Colorado experimented with various prevention methods to prevent mule deer (Odocoileus heminous) and elk (Cervus elaphus) damage to haystacks; nurseries and orchards; livestock feedlots and ensilage pits. These experiments were conducted as management experiments opposed to scientific controlled experiments. The evaluation of each of the treatments involved the perception of efficacy by the cooperating landowners and the author. The cost per foot of the fencing is discussed for each type of treatment as well as the life expectancy for the fence and the cost per ft./yr.(the cost of the materials divided by the life expectancy). All costs are based on the estimated cost to build 40 rods of the fence (660 ft.). These costs include all materials, including the staples and tie wires etc., but do not include cost of labor. The cost of materials are based on the retail price in Colorado for the spring of 1989. The experimental methods are compared to the conventional method of damage prevention fencing using V-mesh, square-mesh and wood panels. The material list and costs for each method are summarized in table 1.

METHODS & RESULTS

Conventional Methods

The following fencing methods are the primary methods that are currently being used to control most of the deer and elk damage in Northwest Colorado.

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[1] Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Marriott Hotel, Fort Collins, Colorado, April 17 -20, 1989].

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Table 1.-- List of items; cost per package unit; number of each item needed; total cost; cost per ft. and cost ft./yr. to build 40 rods (660 ft.) of each type of fence. All costs are retail except for wood panels.

ITEM	PKG. UNIT	PKG. COST	SINGLE UNIT	SINGLE UNIT COST	V-MESH FENCE QTY	V-MESH FENCE TOTAL COST	SQUARE MESH FENCE QTY	SQUARE MESH FENCE TOTAL COST	15 WIRE HI TENSIL QTY	15 WIRE HI TENSIL TOTAL COST	8 WIRE ELEC HI TENSIL QTY	8 WIRE ELEC HI TENSIL TOTAL COST	MOD. ELEC FENCE W/O EXIST. QTY	MOD. ELEC FENCE W/O EXIST. TOTAL COST
Charger, fence, 110 volt (1-25 km.)	ea.	$165.00	ea.	$165.000							1	$165.00	1	$165.00
Clamp, fiberglass T post	50/box	$2.25	ea.	$0.045							72	$3.24	25	$1.13
Clips, dropper	1,000/box	$25.00	ea.	$0.025					2610	$65.25				
Clips, hog ring	100/box	$2.50	ea.	$0.025			165	$4.13						
Droppers, fence stays	ea.	$2.50	ea.	$2.50					174	$435.00				
Fencing, Tensar, plastic mesh, 7 in X 164 ft.	roll	$285.00	1 ft.	$1.738										
Flashing, galvanized steel, 14 in. x 50 ft.	roll	$39.73	5x6 in	$0.142										
Insulating tube	100 ft/roll	$12.00	1 ft.	$0.120							20	$2.40	12	$1.44
Panel, wood, 8 ft. x 8 ft.	ea.	$14.00	ea.	$14.000										
Panels, metal (hog), 6 ft. x 12 ft.	ea.	$25.00	ea.	$25.000										
Post, 10 ft. steel	ea.	$4.59	ea.	$4.590			40	$183.60						
Post, 12 ft., wood, 5 in. top	ea.	$10.87	ea.	$10.870	61	$663.07	21	$228.27	35	$380.45	13	$141.31	10	$108.70
Post, 6 ft. steel	ea.	$2.53	ea.	$2.530									33	$83.49
Post, fiberglass, 10 ft.	ea.	$6.50	ea.	$6.500							9	$58.50	5	$32.50
Post, wood, 7 ft. x 5 in. top	ea.	$2.75	ea.	$2.750										
Rod, grounding, 8 ft. with clamp	ea.	$6.95	ea.	$6.950							1	$6.95	1	$6.95
Rods, steel, 1/2 in. x 7 ft.	ea.	$3.00	ea.	$3.00										
Sleeves, high tensil wire crimping, FW 2-3	100/box	$13.50	ea.	$0.135					94	$12.69	50	$6.75	32	$4.32
Spike, 3/8 in. X 12 in., 50 lbs./box	133/box	$32.20	ea.	$0.244	6	$1.46	6	$1.46	6	$1.46	6	$1.46	6	$1.46
Spring, Tension indicator	ea.	$4.50	ea.	$4.500					1	$4.50	1	$4.50	1	$4.50
Staple, 2 in., insulated	200/box	$38.00	ea.	$0.190							35	$6.65	12	$2.28
Staples, 2 in., galvanized, 50 lbs./box	2,450/box	$23.90	ea.	$0.010	488	$4.88	168	$1.68	465	$4.65	27	$0.27	24	$0.24
Strainer, high tensil wire	ea.	$2.75	ea.	$2.750					15	$41.25	8	$22.00	5	$13.75
Twitch Stick, 1 in. X 1 in. X 48 in., Oak	ea.	$1.50	ea.	$1.500	4	$6.00	4	$6.00	4	$6.00	4	$6.00	4	$6.00
Visqueen, black, 10 ft. x 100 ft., 6 mil	ft.	$47.08	ft.	$0.471										
Wire, 32 in. square mesh X 330 ft.	roll	$66.60	1 ft.	$0.202			660	$133.32						
Wire, 47 in. square mesh X 330 ft.	roll	$85.88	1 ft.	$0.260			660	$171.60					660	$171.60
Wire, barbed, 12 1/2 ga., 1320 ft.	roll	$35.30	1 ft.	$0.027	1980	$53.46	1320	$35.64						
Wire, hi-tensil, 4,000 ft./roll	roll	$72.75	1 ft.	$0.018					9900	$180.18	5280	$96.10	3300	$60.06
Wire, smooth, 12 1/2 ga., 1320 ft./roll	roll	$32.80	1 ft.	$0.025	504	$12.60	504	$12.60	504	$12.60	504	$12.60	504	$12.60
Wire, V-mesh, 72 in. x 165 ft.	roll	$322.00	1 ft.	$1.952	660	$1,288.32								
		COST OF FENCE (660 ft.)				$2,029.79		$778.30		$1,144.03		$533.73		$676.02
		COST PER FOOT				$3.08		$1.18		$1.73		$0.81		$1.02
		LIFE EXPECTANCY (YEARS)				30		30		40		40		35
		COST PER FT/YR				$0.10		$0.04		$0.04		$0.02		$0.03

ITEM	PKG. UNIT	MOD. ELEC FENCE W/ EXIST. QTY	MOD. ELEC FENCE W/ EXIST. TOTAL COST	BAITED ELEC FENCE QTY	BAITED ELEC FENCE TOTAL COST	TENSAR PLASTIC FENCE QTY	TENSAR PLASTIC FENCE TOTAL COST	HOG PANEL FENCE QTY	HOG PANEL FENCE TOTAL COST	VISQUEEN FENCE QTY	VISQUEEN FENCE TOTAL COST	WOOD PANEL FENCE QTY	WOOD PANEL FENCE TOTAL COST
Charger, fence, 110 volt (1-25 km.)	ea.	1	$165.00	1	$165.00								
Clamp, fiberglass T post	50/box	25	$1.13	8	$0.36								
Clips, dropper	1,000/box												
Clips, hog ring	100/box												
Droppers, fence stays	ea.												
Fencing, Tensar, plastic mesh, 7 in X 164 ft.	roll					660	$1,147.08						
Flashing, galvanized steel, 14 in. x 50 ft.	roll			22	$3.12								
Insulating tube	100 ft/roll	12	$1.44	4	$0.48								
Panel, wood, 8 ft. x 8 ft.	ea.											88	$1,232.00
Panels, metal (hog), 6 ft. x 12 ft.	ea.							57	$1,425.00				
Post, 10 ft. steel	ea.												
Post, 12 ft., wood, 5 in. top	ea.	10	$108.70			61	$663.07	58	$630.46				
Post, 6 ft. steel	ea.												
Post, fiberglass, 10 ft.	ea.	5	$32.50	4	$26.00								
Post, wood, 7 ft. x 5 in. top	ea.			2	$5.50								
Rod, grounding, 8 ft. with clamp	ea.	1	$6.95	1	$6.95								
Rods, steel, 1/2 in. x 7 ft.	ea.					3	$9.00						
Sleeves, high tensil wire crimping, FW 2-3	100/box	32	$4.32	4	$0.54								
Spike, 3/8 in. X 12 in., 50 lbs./box	133/box	6	$1.46			6	$1.46						
Spring, Tension indicator	ea.	1	$4.50										
Staple, 2 in., insulated	200/box	12	$2.28										
Staples, 2 in., galvanized, 50 lbs./box	2,450/box	10	$0.10			488	$4.88	580	$5.80				
Strainer, high tensil wire	ea.	5	$13.75	1	$2.75								
Twitch Stick, 1 in. X 1 in. X 48 in., Oak	ea.	4	$6.00			4	$6.00						
Visqueen, black, 10 ft. x 100 ft., 6 mil	ft.									660	$310.86		
Wire, 32 in. square mesh X 330 ft.	roll												
Wire, 47 in. square mesh X 330 ft.	roll												
Wire, barbed, 12 1/2 ga., 1320 ft.	roll					1980	$53.46	1320	$35.64				
Wire, hi-tensil, 4,000 ft./roll	roll	3300	$60.06	660	$12.01								
Wire, smooth, 12 1/2 ga., 1320 ft./roll	roll	504	$12.60			504	$12.60	6600	$165.00				
Wire, V-mesh, 72 in. x 165 ft.	roll												
			$420.79		$222.72		$1,897.55		$2,261.90		$310.86		$1,232.00
			$0.64		$0.34		$2.88		$3.43		$0.47		$1.87
			35		40		10		40		1		5
			$0.02		$0.01		$0.29		$0.09		$0.47		$0.37

V-Mesh Wire Fence

The V-mesh wire fences have been used primarily to control damage to haystacks and ensilage pits. This technique is seldom used on orchards or nurseries because of the high cost of materials and the difficulty of erecting the fencing. The first V-mesh wire haystack fences were installed during the early 1960's.

The V-mesh wire fence is constructed using 12-ft. wood posts set at 12 ft. intervals and double "H-braces" are used for spans that are in excess of approximately 200 ft. (fig. 1). All corner posts are set 4 ft. in the ground and line posts are set a minimum of 3 ft. Sometimes, 10-ft. steel posts will be used in lieu of a wood line posts as a cost saving measure. Using more than one steel post between each set of wood posts is not advisable if elk damage is anticipated. The V-mesh wire comes in heights of 42 in. to 96 in. The 72-in. fencing has been the most commonly used. The completed fence is 8 ft. high. When the 72-in. fencing is used, there is a strand of barbed wire 6 in. off the ground and two strands on top of the V-mesh wire. This fence is extremely strong and will stand up under heavy elk pressure and the effects of snow. However, this fence is difficult to build because of the heavy wire.

Using all 12-ft. treated wood posts and 72-in. V-mesh wire with three strands of barbed wire, the fence costs $3.08 per foot. The fence should last 30 years and would cost $0.10 per ft./yr.

Square-Mesh Wire Fence

The square-mesh or field wire fence has been used primarily to control damage to orchards and nurseries. The fence is considerably lighter then the V-mesh wire fence and is easier to erect. The CDOW first constructed fences of this type in the late 1950's.

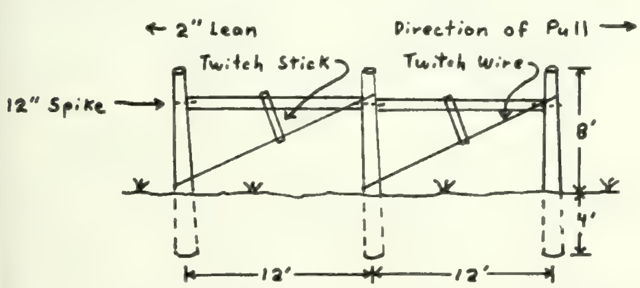

Figure 1.--Construction of a double braced H-brace showing the twitch sticks, twitch wire and brace spike.

The square mesh wire fence is constructed using double braced 12-ft. wood corner posts with line post spaced 12 ft. apart. There are 4 10-ft. steel line posts for every 12-ft. treated wood line post. All corner posts are set 4 ft. in the ground and wood line posts are set a minimum of 3 ft. All steel posts are driven 2 ft. into the ground. Two width of square-mesh wire fencing are used to construct the fence; 47-in. fencing is used on the bottom and 32-in. fencing is overlapped onto the 47-in. fence on the top. The two fences are then joined every 4 ft. with a hog ring. The fence is topped off with 2 strands of barbed wire to make it 8 ft. high. The fence will not stand a lot of pressure from elk. However, by keeping the closest trees or hay at least 10-12 ft. away from the fence, crowding and destruction of the fence by elk should not be a problem. This fence design has proven to be effective in controlling deer damage (Craven 1980, Caslick and Decker 1979).

The fence materials cost $1.18 per ft. The fence should last a minimum of 30 years and would cost $0.04 per ft./yr.

Wood Panels

Wood panels are made from 18 boards (1 in. x 4 in. x 8 ft.) of rough cut lumber. There are 14 vertical boards with 4 horizontal boards nailed to them. Panels were originally intended as emergency haystack damage prevention materials. However, over the years some ranchers and CDOW personnel have viewed the panels as the main method for control of haystack damage problems. Many ranchers are lessees and have refused to erect permanent fencing since they aren't sure how long they would be on the land. Other ranchers like to move their haystacks around each year or don't want a permanent fence in the middle of their hay meadow. One of the big problems with wood panels is their short life expectancy. Some ranches are supplied panels almost every year yet they always seem to need more. Other landowners have used panels for unauthorized purposes such as corrals, roping arenas and stock fences. Some ranchers have thrown panels away or burned them rather than try and replace a few broken boards or loose nails.

Presently, wood panels are being built by the Colorado state prison system at a cost of $14.00 each. This doesn't include transportation costs. The cost per foot is $1.87. Panels rarely last over 5 years, thus the cost per ft./yr. is approximately $0.37.

Experimental Methods

The following are some of the experimental methods of deer and elk damage prevention that have been tried in Northwest Colorado.

Fifteen Wire Non-Electric High-Tensile Wire Fence

High-tensile wire fence systems were first developed in New Zealand over 40 years ago. It has numerous application to game damage control (USS 1980). The CDOW has used this type of fence around haystacks and ensilage pits. The fence is constructed using 12-ft. treated wood line posts that are set every 25 ft. Double braced corner posts are set 4 ft. in the ground and secured with a triple strand of smooth twitch wires and twitch sticks (fig. 1). Corner braces are set to lean 2 in. out of plumb and away from the direction of pull. The proper construction of the "H-brace" corners are critical factors in building high-tensile wire fences since the fifteen wire can exert over almost 2 tons of pull on the posts. If the ground is soft or noncohesive then the corner posts should be set in concrete or triple braced or both. The high-tensile wires are spaced at varying intervals (fig. 2). The completed fence is 8 ft. high and contains 15 wires. Every 5 ft. a fence stay or dropper is installed. These prevent the wire from separating and allowing big game animals to penetrate the fence.

The high-tensile wire is installed in the following manner. Each individual strand of wire is first laid out along the fence. Next, the wire is attached to the corner post by wrapping it around the corner or gate post and crimping the end back upon itself with at least 2 crimping sleeves. The wires are then cut in the middle of each strand and an in-line fence strainer is installed on the wire using crimping sleeves to close the splice. Each wire is then slightly tightened to remove the slack. Then each wire is stapled to the fence posts. It is best to use 2 in. galvanized fence staples. It is important not to drive the staples tight against the wire. The wire should be able to slide freely back and forth between the staple and the post. After all the wires have been stapled, then each wire is tightened to 250 lbs. of tension. A tension indicator spring should be installed to determine the proper tension on at least one of the wires. It acts as a calibration tool to adjust the proper tension for the remaining wires. The final step involves installing the fence stays or droppers every 5 ft. using wire clips (fig. 2). Stays can

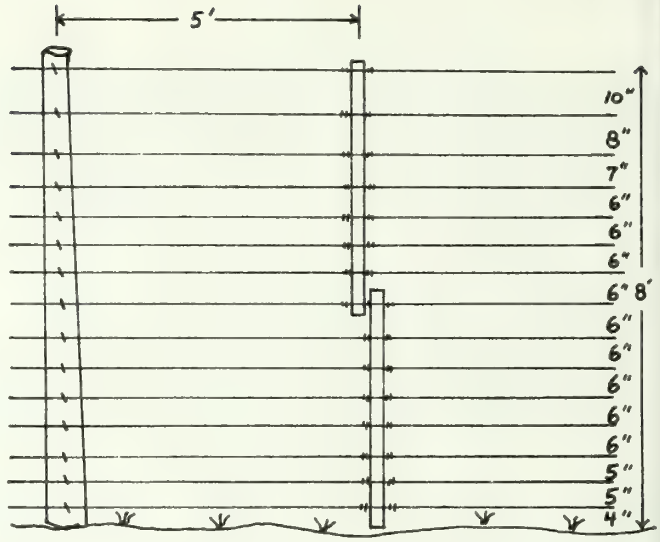

Figure 2--Construction of a portion of a 15 wire high-tensile wire fence showing th wire spacing. The wood posts are space 25 ft. apart with 4 sets of stays between each set of wood posts.

be fiberglass or treated wood. The complete fence should be re-adjusted periodically to maintain the tension. The fence can become too tight in the winter or too loose in the summer. Also, the corner post can settle over time. Re-tightening the fence is as simple as adjusting the in-line fence strainers with a wrench.

The completed high-tensile wire fence i extremely strong and resistant to damage by big game and livestock or even the effects o deep snow. If the fence does become loose, it is a very simple task to re-tighten. The breaking strength of USS Max-Ten 200 high-tensile wire is 1815 lbs., almost twice that of conventional barbed-wire (950 lbs.). This brand of high-tensile wire is type III galvanized so it should last in excess of 50 years in dry climates and still retain 50% o more of its original diameter (USS 1980).

The fifteen wire high-tensile fence costs $1.73 per ft. to build. The fence should last a minimum of 40 years and would cost $0.04 per ft./yr. The maintenance cost of this fence should be very low.

Eight Strand Electric High-Tensile Wire Fenc

Several of these experimental fences have been built to control game damage to orchards, nurseries and livestock feedlots. This fence has also been used to fence haystacks, but it may not be practical under most situations because of lack of AC

electricity or the cost of amortizing a solar or battery powered fence charger over a small stackyard fence. This fence is designed to exclude most big game after they have been aversion trained by the fence. The fence is fairly inexpensive to build but may not be 100% effective.

The fence is constructed similar to the 15 wire fence above except that the post for this fence can be spaced about 50 - 150 ft. apart. Also, cheaper and easier to install, 10-ft. fiberglass post can be used as line posts. However, it's recommended to set a 12-ft. treated wood post at least every 300 ft. The other main difference is that the fence uses alternating negative and positive wires and no fence stays (fig. 3). All the positive wires must be insulated by using insulated staples, tube insulation or fiberglass line posts. The negative wires need to be well grounded with at least 1 6-ft. galvanized steel grounding rod for every 1,500 ft. of fence in dry soil and 3,000 ft. in wet soil (USS 1980). All the positive and all the negative wires are interconnected into a negative and positive electric grid. The positive wires are connected to an electric fence charger that can be powered by AC or DC current. Direct current models can be powered by a battery or a battery/solar charger. The new type fence chargers that are currently available from New Zealand or United States should be used. These can provide over 5,000 volts of shocking power and have a low impedance. The wires should be maintained at the same tension as the non-electric fence (250 lbs.). In theory, animals will attempt to jump between the wires rather then jump over the fence. By doing so, they are subjected to a very high voltage shock. Hopefully, the experience will deter them from entering the fenced area again. The 8-ft. fence should prevent most deer and elk from jumping over the fence. It is important to use the alternating negative and positive wires so that the animal will always be in contact with the ground wire and receive a strong shock even when they are standing on snow covered ground or while they are in mid-air jumping through the fence. These new type electric fences are far superior to the old style and should work much better then the electric fences that Tierson (1969) experimented with to control deer damage.

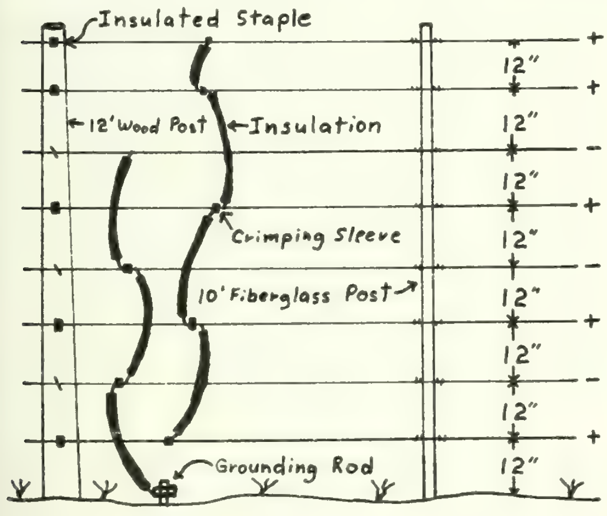

Figure 3--Construction of a portion of an 8 wire high-tensile wire electric fence showing the wire spacing and interconnecting of positive and negative wires.

The cost of the fence using fiberglass line posts spaced at 100 ft. is $0.81 per ft.. This includes the AC fence charger. The fence should last a minimum of 40 years although the fence charger may have to be replaced. The cost per ft./yr. is $0.02. The cost of electricity is additional. U. S. Steel (1980) estimates it would cost $1.00 per month where electricity costs $0.08/kilowatt hour.

Modified Electric High-Tensile Wire Fence

This type of fence is used primarily for orchards and nurseries where an existing square-mesh wire fence is already in place. However, the fence can be constructed from scratch. It provides a very dependable fence against livestock, big game and even small mammals. The electric high-tensile fence is actually constructed on top of the existing fence (fig. 4). The existing corner and gate posts have to be removed and new 12-ft. treated wood posts installed. These posts should be set to the same specification as the double "H-brace" (fig. 1). Next, 10-ft. fiberglass posts are set every 50-150 ft. along the fence. A 12-ft. treated wood posts should be set every 3-400 ft. to make the

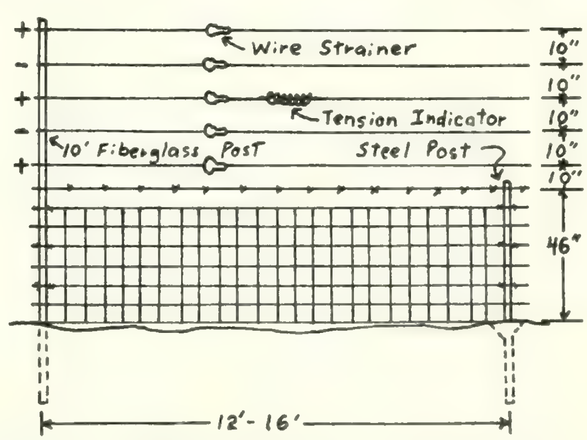

Figure 4--Construction of a portion of a modified high-tensile wire electric fence

fence solid. The bottom portion of the fence consists of the existing square-mesh wire fence, usually 32-47 in. high with 1 or 2 strands of barbed wire on top, set on wood or steel line posts. The upper, or new portion of the fence, consists of alternating positive and negative high-tensile wires. The wires are installed exactly like the electric fence described above (fig. 3). The first high-tensile wire above the old fence should be electric and the top wire should be electric with the remaining wire alternating positive and negative. The wires should be spaced approximately 10-12 inches apart and the top wire should be 8 ft. above the ground. Care should be taken not to allow the first electric wire to sag and contact the existing barbed wire or steel posts. The fence provides a very reliable barrier to prevent livestock and possibly some small game and varmints from penetrating the bottom portion of the fence. The upper portion of the fence can provide a barrier to deer and elk that may try to jump through or over the electric fence wires. This fence can be penetrated by big game, but in theory the experience should be very unpleasant and should deter future penetrations. This fence has the advantage over the all electric high-tensile fence by being at least partially functional at all times and should always deter livestock even when the electricity is turned off. Also, one of the big disadvantages of an all electric fence is vegetation will sometimes ground out the fence. This should not be as big of problem with this fence.

Depending on whether or not there is an existing fence, the cost can vary from $0.64 per ft. with an existing fence to $1.02 per ft. for an all new fence. The entire fence should last a minimum of 35 years. The cost per ft./yr. is $0.02 when there is an existing fence and $0.03 per ft./yr. without an existing fence.

Baited Electric Fence

Kinsey (1976) described using a single strand electric fence, 1 m. above the ground, baited with peanut butter on aluminum foil flags to repel white-tailed deer (*Odocoileus virginianus*). Porter (1983) found this technique to be very effective in reducing white-tailed deer damage to young apple trees in New York and felt the deer were repelled by behavioral conditioning. He did not test the fence on large areas (>5 ha). A similar baited electric fence was tried on a small apple orchard in Palisade. A single strand of high-tensile wire was installed 1 m. above the ground. Seven-foot wood posts were set at each corner and a 5-ft. fiberglass post was set every 75 ft. to support the wire. Aluminum roofing flashing was used instead aluminum foil to make the flags or pockets that held the peanut butter onto the fence. The flags were placed approximately 30 ft. apart. The fence was in place for approximately three months (February to April). The landowner was lax in maintaini the battery that powered the fence charger. However, fence did appear to be somewhat effective in reducing deer damage in the fenced area. Deer tracks around the perimeter indicated where some deer evident came in contact with the wire or flags. These sites contained large amounts of deer hair and torn up ground, indicating a fast retreat. Some deer did cross the fence and continued to browse on the young apple trees. However, the damage did not appear t as severe as prior to the fence.

The cost of the baited fence per foot i $0.34. The main cost is the fence charger. Without the charger the fence would only cos $0.09 per ft. With the exception of the fence charger, the fence should last a minimum of 40 years. The cost per ft./yr. i $0.01. This fence may require a lot of maintenance re-baiting the flags with peanut butter and preventing vegetation from grounding out the fence.

Tensar Plastic Fence

One haystack fence using plastic-mesh fence was installed in Oct. 1986 in the Kremmling area. The fencing is manufactured by The Tensar Corporation, Morrow, Ga. The fencing is 7 ft. high and can be installed similar to V-mesh or square-mesh wire. The CDOW installed the fence on 12-ft. treated wood posts spaced 12 ft. apart. The different fence rolls are spliced together by overlapping the two ends and running a galvanized rod down between the two meshes. The advantage of the fence is that it is very easy to install and easy to work with because of the light weight. However, we are concerned that the fence will break down due to weathering. After 2-1/2 years some strands on the corner posts have already separated.

The cost per foot is $2.88. The the fence should last a minimum of 10 years. The cost per ft./yr. is estimated to be $0.29.

Hog Panel Fence

During the past three years, the CDOW has been using commercial hog panel fencing on an experimental basis. The most commonly used panels are 7 ft. by 12 ft. Although the

panels are made in heights up to 7 ft. and widths up to 16 ft. The panels are secured to 12-ft. wood posts, set about 11-1/2 ft. apart, with fence staples and smooth wire. The fences are relatively easy to construct since no corner "H brace" posts are needed or wire stretching. The panels are very rigid and sturdy. They have been very effective in controlling elk damage.

The cost per foot for the completed fence is $3.43. The fence should last a minimum of 40 years for a cost per ft./yr. of $0.09.

Visqueen (Black Plastic) Wrapped Haystacks

As an alternative to wood panels to control damage to haystacks, CDOW personnel have been experimenting with wrapping the haystacks with visqueen. The visqueen is 10 ft. high and has a thickness of 6 mils. The plastic is attached to the haystacks by placing a pebble, approximately 1 in. in diameter, near the top 1 ft. from the edge and folding the edge over and tying a piece of baling twine around the pebble. The loose end of the twine is then secured to the baling twine on the hay bales. The whole haystack is wrapped in visqueen from the ground up to a height of 7-8 ft. The results have been very encouraging so far for both deer and elk. This technique provides a fairly cheap and easy to install alternative to panels or permanent fencing. It is especially useful when deep snow would limit vehicular access to a haystack making it difficult to use wood panels.

The cost per foot is $0.47. The life expectancy of this material is one season. Thus, the cost per ft./yr. is $0.47.

CONCLUSIONS

1. The effectiveness, initial cost per ft. and the cost per ft./yr., should all be considered in evaluating a fencing system.

2. V-mesh wire fences, hog panel fences and plastic mesh fences (Tensar - brand name) all have a very high initial cost and cost per ft./yr. It would be wise to consider other alternatives before using these materials for permanent fences. Plastic mesh fences have a cost per ft./yr. that is almost 3 times as much as V-mesh and hog panel fences because of their short life expectancy.

3. Square-mesh wire fences are cheaper to build than 15 wire high-tensile fences ($1.18 vs. $1.73 per ft. respectively). Both, offer about the same degree of effectiveness, but the high-tensile wire fence will probably last longer, thus, both have the same cost per ft./yr. ($0.04).

4. High-tensile wire electric fences such as the 8 wire fence and the modified electric fence both offer a low initial cost per ft. and a low cost per ft./yr. rating. The fences are not completely effective in preventing all damage but offer a cheaper alternative and a long term solution.

5. Electric high-tensile wire fences require more maintenance but may provide a good alternative for preventing severe damage that occurs for only a short period of time during a calendar year, such as heavy winter browsing to nursery stock.

6. The baited electric fence has shown some promise and may be a viable alternative to 8 ft. fencing when the fence will only be needed for a few years, such as when a new orchard is being established in close proximity to a much larger mature orchard. More experimentation is needed.

7. Visqueen (black plastic) can be a cheaper and effective alternative to wood panels to control haystack damage. More experimentation is needed.

8. Because of their short life expectancy and high cost per ft./yr., wood panels should only be used as emergency prevention methods. Permanent fencing using square-mesh or high-tensile wire should be used to solve continuing problems because they cost about 80-90% less over their life expectancy.

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The Use of DMA to Reduce Robin Depredation on Cherries[1]

Leonard R. Askham and John K. Fellman[2]

The use of a biorational pesticide, Dimethyl Anthranilate (DMA), was investigated for possible use as a robin repellant in an Eastern Washington Research orchard. Applied in low concentrations (2, 4, and 8% with surfactant), robin depredation was reduced an average of 75%. A double-blind taste test showed no consumer aversion for fresh fruit sprayed with DMA two weeks before harvest. Initial residue analyses show DMA concentrations in sweet cherries to be undetectable (<500ppb) using the sensitive methods of fused-silica open tubular (FSOT) capillary gas chromatography (GC) coupled with flame-ionization detection.

INTRODUCTION

Each year, the state of Washington produces about 58,000 tons of the fresh sweet cherries, or 60% in the United States. Prices for this crop during the last five years have ranged from a low of $689 to a high of $1,030 per ton ($864 five year average). These revenues account for approximately $44.9 million of the states' total agricultural income (Schotzko, 1989; U.S.D.A., N.D.).

As with most soft fruit crops, cherries are prone to bird depredation. In most areas damage is primarily caused by robins (*Turdus migratorius*), common grackles (*Quiscalus quiscula*) and starlings (*Sturnus vulgaris*) (Guarino, 1972) although other species have been known to feed upon the crop at various times. Until recently, the problem was resolved by spraying the ripening crop with methiocarb (a chemical repellent containing 4-[methylthio]-3,5-xylyl N-methylcarbamate) shortly before harvest. In the initial studies, depredation on the cherries, after the material was applied was significantly reduced ($p>0.001$) between treatment and controls. Random samples in sweet cherries showed that the controls received about 5 times as much damage as the treated trees (36% vs. 7%). With sour cherries, over 50% of the fruit was damaged in the control plots while only 20% was damaged in the treated plots.

In 1988, methiocarb (Measurol ^{tm}) was withdrawn from the United States market by the manufacturer at the request of the Environmental Protection Agency (EPA) because concentrations of chemical residues found in the ripe fruit exceeded standards established by the federal government. With this material removed from the market, few, if any effective repellent materials and methods remain available to the grower. Unless a viable alternative is found, millions of dollars in lost revenues will be incurred by the producers.

With the depredation of a monoculture by a protected species (such as robins) a non-toxic biodegradable compound with little or no discernable residual taste to the ultimate consumer must be found to replace the banned repellent. One possible alternative is dimethyl anthranilate (N-methyl methyl anthranilate). Dimethyl anthranilate (DMA) is a colorless to pale yellow liquid with a concord grape-like odor that is derived from methylation of methyl anthranilate or esterification of N-methyl anthranilic acid. It has a specific gravity of 1.132 to 1.138, is soluble in 3 or more volumes of 80% alcohol, benzol benzoate, diethyl phthalate, fixed oils, mineral oils and volatile oils (Arctander, 1969). As a naturally-occurring compound, it meets established criteria as a biorational pesticide pursuant to the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (Federal Regisister, 1979).

DMA, long used as a food and drug flavoring additive, has been found to be an effective taste repellant when applied to different food sources in concentrated doses. In a series of tests conducted by Mason and Arzt (N.D.), caged starlings fed progressively less on treated lipophyllic starch treated with DMA as the concentrations were increased from 0.4 to 1.6%. In another series of tests, Mason, *et al* (1985) found that "DMA substantially reduced consumption ($P=0.05$)" during the treatment periods and suggested that the material "might be used as a feed additive to reduce bird depredation without primary or secondary hazards to non-target animals."(p. 636) with concentrations as low as 0.2%. Mason and Bean (1987), however, found that 2% concentrations were necessary to repel Mallard ducks (*Anas platynchos*) and Ring-necked pheasants (*Phasianus colchicus*).

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With this information, a series of trials were established to test differing concentrations of pure (98.7%) DMA on various soft fruit crops. The objectives of the first trials were to: 1) determine if DMA, when applied to soft fruit, would deter birds from consuming a significant quantities of the crop. 2) test whether the consumer could taste the difference between treated and non-treated fruit, and 3) analyze the harvested crop for detectable residues.

MATERIALS & METHODS

Pen Trials

To determine if DMA, when applied in reduced concentrations to soft fruit, would repel birds from the crop, a series of trials using caged birds and ripe grapes was established. In the caged trials, 120 starlings were placed in a 20 X 60 X10 foot wire screened outside aviary for 7 days for pre-trial conditioning. Because fresh cherries were not available when the trials were started, chenin blanc and cabernet grapes and applies were placed in 10 X 14 X 2 inch white enamel pans inside the aviary between 8 and 9 A.M. each day. Cooked french fried potatoes were placed in the same type of trays at noon and left for the remainder of the day. Any residue food sources were removed the following morning and the process repeated. Water was provided, *ad lib*, during the entire period for all trials.

To establish the effective application rate of DMA on small fruit, two groups of twenty starlings were randomly selected from the pool, placed in two identical aviaries, as described above, and preconditioned for an additional two days. The same feeding reqime and conditions as established for the larger population were continued, except that all food was removed at dusk. Each morning between 8 and 9 A.M. pre-weighed samples of grapes dipped in formulations of either 20, 40 or 80 ml of DMA and 3 ml of 95% ETOH and distilled water (2, 4 or 8%, 1 liter solutions) were placed in the white enameled baking pans, paired with non-treated samples, and left for the remainder of the day for 5 consecutive days. Throughout the trails, additional pans of pre-weighed untreated samples were placed in screened enclosures outside of the pens to establish desiccation rates. At noon, 2.5 kg of cooked french fried potatoes were placed in two enameled pans and left in the cages. At 5 P.M. all food was removed from the aviaries, inspected, weighed and recorded.

Field Trials

The following spring, two mature Van cherry trees were treated with 40 ml of DMA and 13 ml of Regulaid (as a surfactant) per 1000 ml fresh water. The amount was doubled for one additional tree. Approximately 1.5 liters of test material was placed on each tree with a Solo (tm) back pack air blast mist sprayer. None was placed on three trees which served as controls for the experiment. The remainder of the orchard was treated with Measurol.

The trees were monitored each day for color change, phytotoxcicity and predation. Immediately prior to and for fourteen days after treatment two, 24 inch branches were cut from the outside of each tree (between the tree rows), 6 feet from the orchard floor. Fruit from each branch was divided into one of three categories, whole and unmarked, partially eaten or marked, or missing. Marking was defined as any blemish that might have been caused by birds feeding on the fruit (excluding cracking). Missing fruit was defined as the presence of a whole green stem, without a desiccated flowering head at the pedestal, where a ripening fruit was borne. Torn remnants of a fruit were often found on these pedestals. The fruit from each category was then counted, recorded, removed from the branch, sealed in double plastic bags, and stored at -40°C until processed.

Taste Trials

Before freezing, 6 oz. sub-samples were selected from each of the treatment groups for taste analysis. Three plates, each containing six fresh cherries from each treatment group, were placed in front of six tasters, three of whom had been informed about the experiment. All were asked to rate each group for sweetness, flavor, and note any abnormal taste.

Residue Analysis

Representative samples of treated cherries were frozen for later extraction and analysis. Cherries were thawed, blended with distilled water, and clarified by centrifugation at 80 g's (500 rpm) for 1 min. Supernatants were filtered, brought to constant volume and stored at -40°C until analyzed.

Initial studies were undertaken with thawed aqueous solutions using purge-and trap cryofocusing injection into a fused-silica open tubular gas chromatograph (FSOT/GC). Despite its apparent volatility, DMA condensed on the glass surfaces of the injection apparatus, forcing the abandonment of this direct procedure. Aqueous samples were then extracted with acidified hexane. The concentrated organic phase was injected into a Hewlett-Packard 5890A Gas chromatograph equipped with a flame-ionization detector and a model 3396A digital integrator. Chromatographic separation was performed on a 30mx0.32mm I.D. DB-1 FSOT column (J&W Scientific, Rancho Cordova CA) held under the following conditions:

- -initial temperature 145°C
- -temperature immediately increased 20°C/min to a final temperature of 280°C and held for 2 min.

Split injection was performed with an inlet split ratio of 60:1 at a helium carrier gas velocity of 37cm/sec. DMA eluted at 256°C with a retention time of approximately 5.6 min. under these conditions. Putative indentification of DMA was by co-elution of standards.

Studies are currently underway to ascertain the difference, if any, between purge-and trap and extraction/direct injection methods.

RESULTS

Pen Trials

Wine grape consumption by the starlings was considerably less when treated with DMA (Fig. 1). The 2% solution reduced feeding approximately 29 to 59%. The 4% solution reduced consumption approximately 46 to 61% while the 8 % solution decreased consumption 94 to 95%. There was no dessication of untreated grapes outside the aviaries.

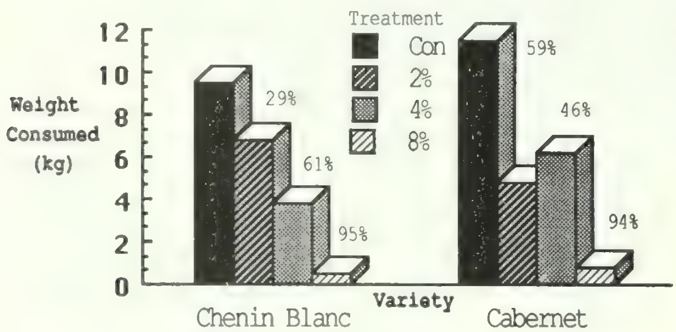

Figure 1. Consumption (kg) of Chenin Blanc and Cabernet Wine Grapes Treated With Three Concentrations of DMA During Choice Feeding Trials with Starlings

Field Trials

Prior to treatment, 9.8% of the fresh fruit on all of the trees in the experiment had either been damaged, eaten or removed by robins (Fig. 2). After treatment, depredation on the fruit on the control trees had increased to 14.9% but had decreased to 6.4 and 3.5% respectively for the 4 and 8% treated samples. None of the trees treated with the 4% solution exhibited any signs of discoloration, cracking or phytotoxcicity (Fig. 2). However, the tree treated with the 8% solution the leaves, stems, branches and fruit were severely burned and discolored where they had been drenched during application. The remainder appeared to be normal.

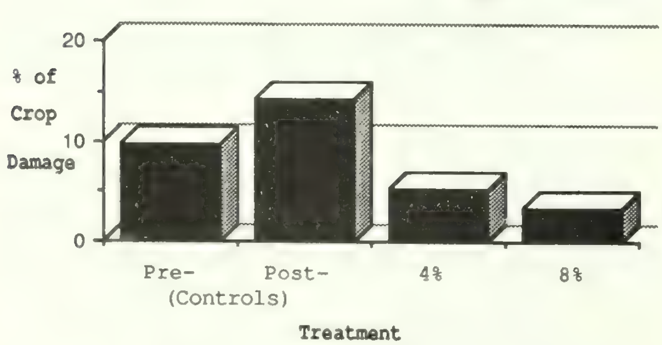

Figure 2. Bird Damage to Sweet Cherries Before and After Treatments with DMA

Taste Trials

No taste differences between treatment groups were noted by the panel. All stated that the first cherry tried was the sweetest, the second less so, and the remainder about the same. None reported any abnormal flavor differences, particularly those that had been informed of what to look for prior to the study.

Residue Analysis

Representative chromatograms of a sweet cherry extract and an extract fortified with a known amount of DMA are depicted in figures 3 and 4.. No DMA was detected in the fruit treated with the 4% and 8% solutions The data for both samples were the same (Fig. 3). Figure 5 depicts the effect of fortification with 1 ppm.

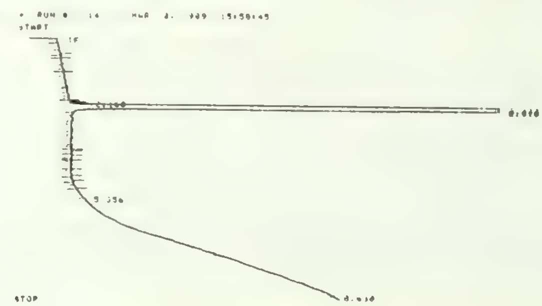

Figure 3. FSOT/GC of extracts from Van Cherries treated with 4 & 8% solutions of DMA. (Arrow indicates position of authentic materials for each sample. Major peak indicates solvent presence)

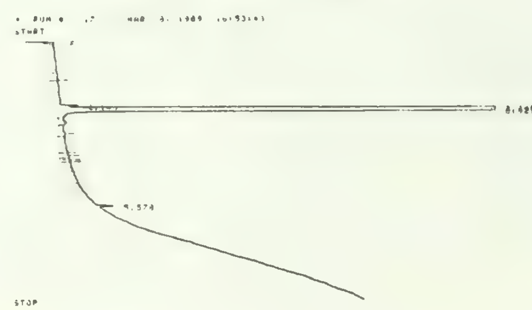

Figure 4. FSOT/GC of Fig 3 fortified with 1 ppm DMA.

DISCUSSION

The use of low concentrations of DMA to reduce bird depredation on cherries appears to be a viable alternative to using methiocarb as a chemical repellant. While the trials were limited, each indicated that the chemical properties of the tested material were well within established tolerances.

During the pen trials, feeding on the grapes treated with 4 & 8% solutions was significantly

reduced over those that had been treated with 1 & 2% or not treated at all. After the pans of fruit had been placed in the aviaries and the researcher had left the area, starlings would immediately fly to each of the treatment sites. When untreated samples had been placed in each pan, the birds would devour as many grapes as possible at one time unless frightened or forced from the site. When samples treated with 4 and 8% solutions were placed, in the pan the birds would pick one grape from a cluster, spit it out, look at the remaining grapes and then fly to another pan where other birds were freely feeding.

None of the concentrations discouraged the starlings from feeding on the apples. Feeding was accomplished by first pecking a hole in the outer layer of the fruit and then removing the pulp and seeds. When finished, each apple had been hollowed out until only the skin, stem and a 1 in. hole remained. These observations indicate that the targeted bird must be able to remove an entire fruit from the stem to receive the full taste of the repellancy compound. Where small amounts of the treated area are removed, when the fruit is pecked, the concentrations tasted or ingested do not appear to be significant enough to cause a taste aversion.

In the field trials, the feeding on non-treated cherries increased a little over 30%. Feeding on treated cherries decreased 62 to 76% respectively for the 4 & 8% treatments.

The taste test showed that there were no discernable taste differences between the treated and the untreated fruit. None of the people (including those who knew that some of the fruit had been treated with DMA) who participated in the trials were able to detect any adverse flavoring from the DMA.

Initial residue studies suggest little retention of DMA inside sweet cherries harvested 2 weeks after orchard treatment. More detailed residue studies are currently underway. One possibility is the sampling methodology precluding analysis of skin residue. It is likely that DMA does not penetrate the surface of sweet cherries. In light of the apparent dissipation of DMA residues coupled with the chemical's long-standing history as a safe flavor additive, further studies of DMA as a Measurol^{tm} replacement may foster the implementation of a lower-input, low impact vertebrate control strategy for sweet cherries.

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Seasonal Effects on Control Methods for the Great-Tailed Grackle[1]

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Efficiency of methods used to control damage to citrus fruit by great-tailed grackles was found to vary considerably from season to season. From April - July, the birds congregated in small breeding colonies where they were susceptible to baiting and poisoning. From August - October, the birds could be baited in to and poisoned at watering sites. Intensive shooting and use of pyrotechnics were also used successfully at this time of year to control damage at groves with high grackle concentrations. From late October - March, birds moved over wide areas each day, and were easily frightened from groves by pyrotechnics and shooting. No single method is available at present to control the entire population or to protect a given grove through all seasons.

INTRODUCTION

The great-tailed grackle (Quiscalus mexicanus) is an abundant permanent resident of the lower Rio Grande Valley of Texas. Though numbers of the birds change from season to season, there is no time when this species is not present. As a result, grackle damage to citrus and other fruit and vegetable crops is a year-round phenomenon.

During the course of our work in the Valley, 8 methods were considered to determine their effectiveness in limiting grackle damage to citrus: 1) monofilament line 2) reflective tape, 3) eyespot balloons 4) pyrotechnics (propane cannons and shotgun scare shells), 5) poisoning of birds, 6) shooting birds, 7) grackle nest destruction, and 8) spraying birds with the wetting agent, PA-14. Details of the methods and results of the research on the effectiveness in reducing grackle damage to fruit of monofilament line, reflective tape, eyespot balloons, pyrotechnics, and poisoning with PA-14 and DRC-1339 are presented elsewhere in this volume (Tipton et al. 1989a, Tipton et al. 1989b).

In this paper, we present the results of control efforts using some additional control techniques, and consider the effectiveness of all of the techniques tested as affected by the seasonal changes in movement and behavior of the great-tailed grackle in the lower Rio Grande Valley of Texas.

STUDY AREA

The lower Rio Grande Valley of Texas (fig. 1) is the fertile delta region of the Rio Grande River (referred to hereafter as the Valley). The rich soils of the delta cover approximately 1,194-km^2 in Texas. We travelled and worked throughout the Valley, but most of our radio-tracking and damage assessments were done in Hidalgo and Cameron counties. Ninety-eight percent of the Valley land is in agriculture of one form or another (George 1985), including 11,760-ha of citrus (Waggerman 1988). Prior to the freeze of December 1983, citrus covered more than 30,000-ha (R. Prewitt, pers. comm.). Natural habitat (thorn forest, savanna, riparian forest) occupies an estimated 4,700-ha in the Valley (Waggerman 1988), and these areas are in various successional stages; none is in pristine condition.

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[1]Paper presented at the ninth Great Plains wildlife damage control workshop [Colorado State University, Fort Collins, April 17-20, 1989].

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METHODS

Shooting was used in conjunction with pyrotechnics as a control device in selected groves where grackles occurred during the day at densities > 10 birds/ha. Control efforts were performed in 1 of the groves (Fox) during the breeding season, 2 groves in the summer post-breeding period (Fox and Moorefield), and 5 groves during the winter period.

Fruit Damage Reduction Using Shooting and Pyrotechnics

Breeding season procedures involved making counts in the grove on 3 non-successive days using a shotgun scare shell ("Shot Tell" scare shells, Reed Joseph International Co., Greenville, Mississippi). These shells are fired from a 12-ga shotgun. They explode about 50-m downrange with a loud (100-db) noise. Damage to fruit in the grove was assessed monthly from July until harvest, which usually occurs in November, though some groves are not harvested completely until February. Fifteen trees were randomly selected in each grove and the total number of fruit damaged by grackles and the undamaged fruit were counted on each tree. Four technicians entered the grove on the first Monday after pre-treatment damage assessment was completed, and shot as many grackles as possible from 0800-1000-h each day, Monday-Friday, for 2 weeks. At 1000-h, they placed 2 propane cannons in the grove. Propane cannons (Margo Supplies Ltd., Calgary, Canada) are metal tubes roughly 1-m in length that stand about 1-m off the ground on a tripod. They are connected to a 10-kg propane tank. A timed, electronic spark ignites a small amount of propane at pre-set intervals producing a loud, "thunderclap" sound of 80-120 db. Two, multi-detonation cannons were placed in the grove, 1 in the center of the north half, the other in the center of the south half. These cannons automatically fired at 2-5-min intervals and were run from 1000-h until dark during the 2 week treatment period. On Monday, Wednesday and Friday of the third week, the grove was entered and a single scare shell was fired over the northern half and the southern half of the grove, and the number of grackles taking flight was counted. On each Monday thereafter, scare shells were fired and grackle counts made. When counts reached 25% of treatment pre-counts, a 1-week treatment of shotgun and propane cannons was repeated.

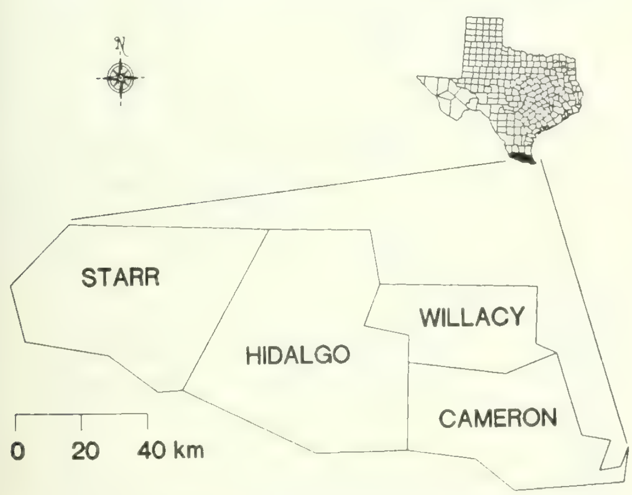

Figure 1.--Map of Texas showing location of the lower Rio Grande Valley.

During the 1988 post-breeding and winter seasons (Aug-Dec), we searched for groves having > 10 birds/ha on which to try our shotgun-scareshell-propane cannon technique. The method was used on 2 groves during the summer post-breeding period (Aug 1988), and on 5 groves during the winter season (Nov 1988). The method was drastically alterred during the winter season due to dramatic changes in the behavior of the birds. During the winter, when a grove was located that contained birds, several scare shells and shotgun shells were fired in a short period (10-20 min), and the number of birds leaving the grove vicinity was counted. The grove was then re-visited at 2-h intervals the rest of the day, and the number of birds in the grove was counted either by using scare shells or by driving up and down the rows and counting numbers of grackles flushed. The grove was then checked once/day for the next 5 days in the same manner.

Fruit Damage Reduction Using Nest Removal

To prevent establishment of breeding colonies in citrus groves, a grackle nest removal procedure was performed in 2 groves with a history of high grackle nesting densities (> 10 nests/ha), and high damage rates as recorded during the 1987 season: Nonmacher (0.8-ha) and Signez (.3-ha). On 23 March 1988 all grackle nests, old and new were removed from both groves. New grackle nests were counted and removed at biweekly intervals thereafter until no new nests were found in either grove (17 June 1988). Fifteen trees were randomly selected in each grove for assessment of damage to fruit. The assessment was performed monthly on the same fifteen trees from July - October 1988. These results were compared with damage assessments performed on the same groves in 1987.

Damage to citrus fruit by grackles was assessed throughout the project, from January, 1987 - January, 1989. Initially (Jan - Oct 1987), a study was done to determine the extent of damage to the citrus industry done annually by the birds, and to idenify the major factors correlated with grackle damage to citrus (e.g. proximity to roosting sites, grove isolation) (Johnson et al. 1989). Subsequently, damage assessments were performed on treatment and control groves for each of the different treatment experiments. Damage was assessed monthly in treatment and control groves from July until harvest (Nov - Feb depending on grove).

Grackle Movements

We made daily observations on the movements and behavior of great-tailed grackles throughout 2 complete annual cycles. In addition to these observations, we placed radio transmitters on selected individuals during the different seasons of the year. Birds were captured using a variety of methods including: Australian crow traps, cannon nets, light traps, and mist nets. The most commonly used method involved placing mist nets (12-m x 2.6-m, 61-mm and 121-mm mesh) on 5-m, telescoping poles in areas of high activity, e.g. feed lots (winter), roost sites (winter), nesting sites, and watering sites (summer).

Each captive was banded with a U.S. Fish and Wildlife Service numbered, aluminum band, and given a unique color band and patagial tag sequence for individual identification in the field. A 6-gm radio transmitter (at frequencies between 150.850-151.450 MHz) was attached using a figure 8 harness (Rappole et al., MS). Each transmitter (Custom Telemetry, Athens, Georgia) was 2.5-cm x 1.5-cm x 1-cm with a 23-cm whip antenna, powered by a lithium battery. Average battery life was 6 weeks. Reception distances were highly variable depending on the amount of interference by other radio traffic and power lines. However, normally we were

able to pick up signals at distances of 1.5-2.0-km on the ground, and 3.0-5.0-km from the air using an LA 12, 12-channel receiver, 4-element Yagi antenna with 3-m extension pole, and Dave Clark headphones. Birds were located 2-3 times daily as other duties allowed.

RESULTS

Fruit Damage Reduction Using Shooting and Pyrotechnics

The breeding period for the great-tailed grackle in the lower Rio Grand Valley is early April to mid-July, during which time grackles show considerable site tenacity to breeding colony sites. This fact is illustrated by the results of the shooting and pyrotechnic treatments applied to Fox Grove (table 1). This grove had a density of 16.3 grackle nests/ha in June, 1988 when this control procedure was initiated. Furthermore, there was a history of early season (Jun-Aug) grackle damage to fruit from 1987 (table 2), presumably due to the high grackle populations present in the grove during the summer breeding period. Scare shell counts performed on 3 non-consecutive days prior to the initiation of the intensive shooting and propane cannon work showed mean densities of only 2.9 birds/ha. However, 425 birds were shot in the grove during the 14 day period of morning shooting and cannon work, including 22 on the last control day. Post-treatment counts performed in the grove using scareshells on 3 consecutive days showed mean densities of 0.8 grackles/ha.

Table 1.—Shotgun-pyrotechnic control efforts.

Grove(ha)	Date initiated	Estimated Birds/ha[1]	Control period
Fox (16.0)	6 Jun 1988	27	14 days
Fox (16.0)	1 Aug 1988	9	14 days
Moorefield (40.0)	2 Aug 1988	10	14 days
Valverde (4.0)	9 Nov 1988	80	5 min
Klements (0.4)	17 Nov 1988	280	10 min
Taylor (2.8)	18 Nov 1988	90	20 min
Trenton (8.0)	3 Nov 1988	40	10 min
England (5.6)	3 Nov 1988	40	10 min

[1]Based on number of birds killed for Fox and Moorefield, and number of birds counted in the air for the remaining groves.

Grackles also showed a great deal of tenacity to colony sites during the period immediately following breeding (Aug-Sep) as well, particularly those where drinking water, usually in the form of irrigation ditches, was available. In August, when the treatment had to be repeated in Fox Grove, 146 birds were killed in an 8-day period. Table 3 shows the estimated cost of the shotgun-cannon treatment at Fox Grove during June. Total cost/ha of the treatment was $25.69/ha.

Effectiveness of the shotgun-pyrotechnic treatment increased sharply in the winter months (Nov-Mar) when only a few scare shells were sufficient to cause all of the grackles in a 500-m radius to leave the area within minutes (table 1).

Fruit Damage Reduction Using Nest Removal

The basic conjecture underlying the nest removal treatment was the same as that for the shotgun-pyrotechnic treatment, i.e. that disruption of breeding colonies in citrus groves would cause desertion of the colony and subsequent reduction of early season (Jun-Aug) damage to fruit. However, the birds did not readily abandon colonies in either case. Despite weekly removal of nests from 23 March - 17 June 1988, birds continued to build nests in the colony until the final week of the treatment (fig. 2). Nor did the treatments appear to have a significant positive effect on fruit damage (table 4).

Table 2.—Effects of Shooting, Pyrotechnics, and Cannons in breeding colonies on damage rates to citrus fruit.

Treatment	Year	Mean damage % by month			
		Jul	Aug	Sep	Oct
Moorefield - S[1]	1988		21.7	22.1	21.6
Moorefield - NS[2]	1988	17.3[3]			
Fox - S	1988	3.1	9.3	9.5	3.9
Fox - S	1987[4]	5.3	8.8	18.2	21.4

[1]S = Intensive shooting as described in Methods.
[2]NS = No shooting. We had no damage assessment from Moorefield Grove for 1987. We performed a damage assessment in July before beginning shooting procedure.
[3]Pre-treatment damage levels.
[4]Damage levels from previous year.

Table 3.—Estimated cost of pyrotechnic and nest removal treatments.

Treatment Type	Item	Cost/ units($)	Total Cost($)	Cost/ hectare($)
Pyrotechnic	shells	0.13	173.71	10.85
	labor	3.35	279.74	14.34
	cannons[1]	2.00	4.00	0.25
	propane	2.00	4.00	0.25
	total		461.45	25.69
Nest removal	labor	3.35		

[1]Cost/cannon was $450.00 in 1988 and was amortized over the estimated 20-yr lifespan of the cannon.

Table 4.—Effects of nest removal on damage rates to citrus fruit.

Treatment	Mean Damage % by Month			
	Jul	Aug	Sep	Oct
Nonmacher - T[1]	1.1	2.6	2.2	2.7
Nonmacher - C[2] (physical pair)	1.2	1.4	1.5	2.1
Signez - T	23.0	32.2	37.5	30.1
Signez - C (temporal pair)	15.0	17.3	40.5	37.4

[1]T = Treatment (nest removal).
[2]C = Control (no nest removal).

Annual Cycle of Behavior and Movements of the Great-tailed Grackle

Males begin leaving the large winter roosts in late March and early April, dispersing to breeding sites. These sites are widely dispersed throughout the Valley. In central Hidalgo County alone we located 56 nesting colonies in May, 1987. The colonies vary in size from 2-3 males with 5-10 females and nests in a single hackberry tree at a residence to thousands of nests in extensive thorn forest and citrus groves. Nests are deep, bag-like structures usually placed in the crown of a tree, 4 to 5-m above the ground. Preferred trees for nest placement include ebony (Pithecellobium flexicaule), brazil (Condalia obovata), hackberry (Celtis laevigata), granjeno (Celtis pallida), mature citrus, and giant reed (Arundo donax). Nest building begins in early April and reaches a peak in late April and early May (fig. 2). Females perform all of the brood-rearing duties: nest-building, incubation, brooding, feeding of hatchlings, and feeding of fledglings. Males defend perch sites in the colony and normally take no part in brood-rearing activities, although on one occasion we observed a male grackle defending a nest from an intruding female grackle. The nest had been left vacant by a radio-tagged female who had left to locate food for her newly hatched young. Female grackles readily canibalize the nests of their neighbors.

Radio-tracking data show that adult males during the breeding period (Apr - Jul) seldom move more than 1-km from their perch site, day or night, and spend more than 90% of their time at the site, as illustrated by the movements of male GP 104 (fig. 3). This bird was tracked from 22 April - 7 May and was never found more than 100-m from his perch site, which was located in the top of a mesquite (Prosopis glandulosa) at Garza Brush. Some males, presumably mostly second year birds, tend to show little or no fidelity to a colony or perch site, and spend much of their time at watering or feeding sites. This was the case with GP 109 who was captured at a temporary pond formed by irrigation water across the road from Garza Brush, a chaparral nesting colony. He spent most of his time in a barnyard and pasture 2-km W of his capture point (fig. 3). He was tracked from 22 April - 26 May.

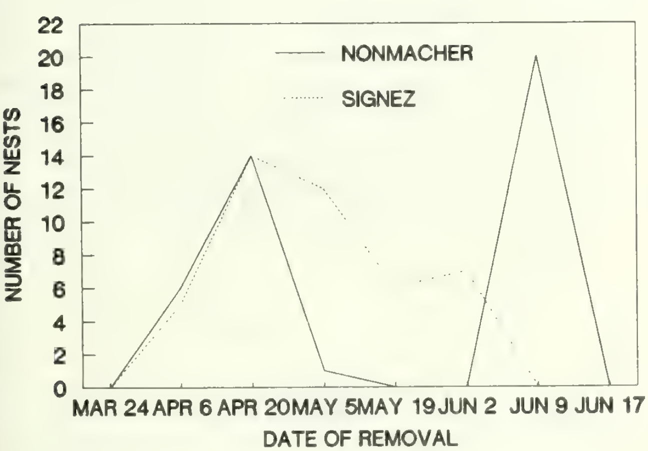

Figure 2.--Graph of bi-weekly counts of nests removed in 2 groves with high grackle nesting densities.

Nearly all females are involved with nesting and rearing of young from April - July, with a few birds continuing to nest into August. During this period, they seldom move more than 1-2-km from the nest site. The movements of female GP 110 are illustrative. She was captured at a pond in Garza Brush on 2 June and followed until 30 July (fig. 3). For most of this time, she made increasingly frequent trips between her nest near the road and the pond 1-km N of her nest, bringing food and water to her nestlings. However, on 28 July, she flew 6-km N to Wallace Marsh to roost and never returned to Garza Brush, presumably because her offspring were independent. Thereafter until her transmitter failed she was found in agricultural fields feeding with other grackles and roosting at night in the marsh with about 10,000 other grackles.

When the young hatch, they are fed primarily Lepidoptera larvae, which the females procure from nearby fallow fields. Seventeen females shot while returning to the nesting colony in the thorn forest of Garza Brush on Monte Cristo Road all had Lepidoptera larvae in their beaks. Females nearly always stop at a watering site on their return with food for their young, and dip the food into the water before flying on with it to the nest. Normal daytime temperatures exceed 37 C in the Valley from June - September, so that water in the vicinity of a nesting colony is a critical factor.

Incubation lasts an average of 14 days, after which the young spend an average of 12 days as nestlings. After fledging, they accompany the mother for several days. They then join flocks of other newly independent young that congregate in hedgerows, brush patches, and cane stands in the immediate vicinity of water. During the post-breeding period from mid-July to September, grackles seldom move far from a watering site during the day. Both the adults and the young perform the pre-Basic molt during this time. In the evening, however, they collect in numerous small roost sites, generally located at marshes, cane fields, residential areas, native thorn forest; anywhere that provides a combination of tall, dense vegetation fairly close (1-2-km) to good feeding and watering sites. The movements of GP 166, a hatching year female followed from 10 August - 29 September, illustrate characteristic movement during this period (fig. 4).

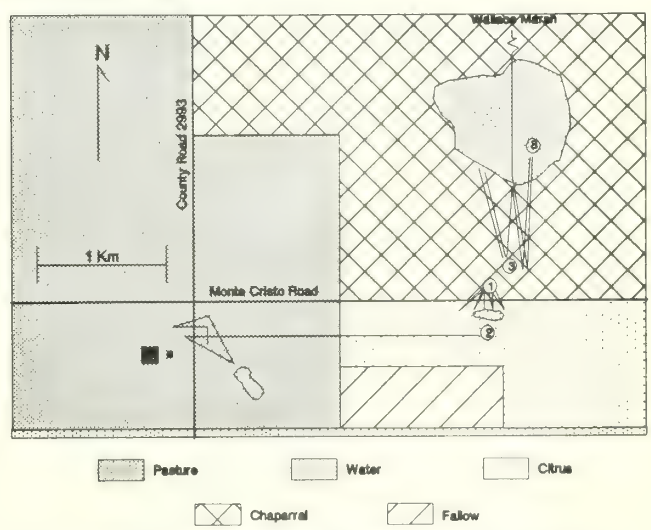

Figure 3. Movements of adult males GP 106 (1) and 109 (2) and adult female GP 110 (3) radio tracked the June–July peak of breeding.

When the weather begins to cool in October, the birds range over much larger distances, and they begin to coallesce into larger roost sites, abandoning many of the smaller roosts.. Instead of restricting their activities to a 1-2-km circle around a dependable water supply, they fly several km in search of food. At this time, and throughout the winter period (Oct-Mar), flying birds readily respond to the presence of other grackles feeding, so that a small flock following a tractor turning up grubs in an agricutural field can become a flock of several hundred individuals in a matter of minutes. Radio-tracking data on female GP 178 illustrate this movement (fig. 5). She was captured on 29 September at a roost in sugar cane. For the next week she moved from the roost to weed fields in the vicinity, but made a 20-km flight to the west on 14 October.

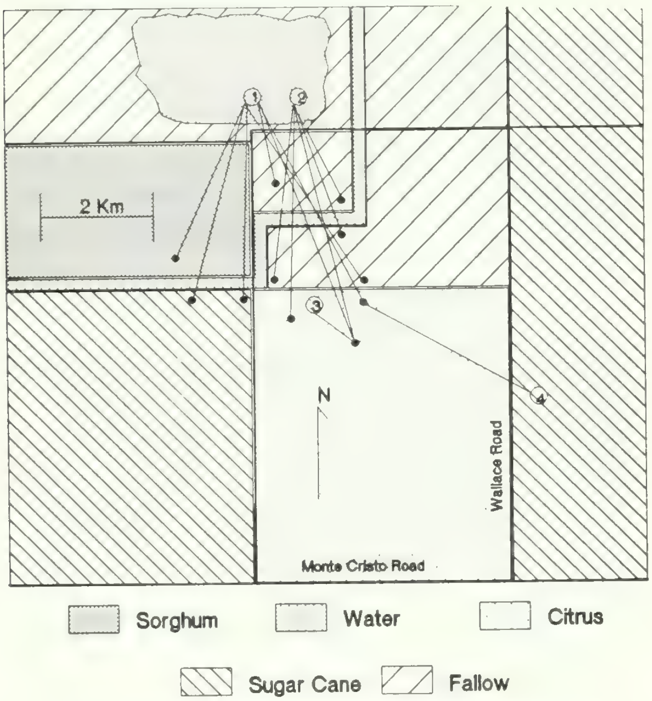

Figure 4. Movements of hatching year female GP 166, tracked from 10 August to 29 September. Circled numbers are roost sites.

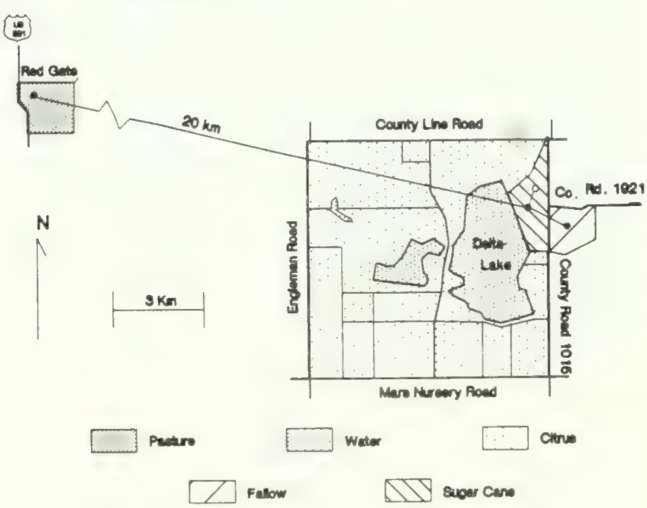

Figure 5.—Movements of hatching year female GP 178 tracked from 29 September to 14 October.

There is an influx of birds from the north in November. Unfortunately, we were unable to document the amount of movement into the area, but migration clearly increases the number of birds wintering in the Valley from November until March when the winter roosts break up.

DISCUSSION

The annual cycle of the great-tailed grackle in the lower Rio Grande Valley of Texas has clear effects on the efficacy of damage reduction efforts in citrus. Nest removal had no measurable effect on reducing fruit damage because it did not cause the birds to abandon the grove. Males continued to display in the groves and were able to attract females right through the nesting season, despite the lack of success in rearing young. Grackle populations remained high in the groves until July so fruit damage continued until that time, at which point a large percentage of the fruit had already been damaged. We conclude that nest removal on is not a suitable method for controlling damage to citrus.

Disruption of the breeding colony by shooting does reduce the rate of damage to fruit. However, this method would be much more effective if instituted early in the season, i.e. late March or early April, before male territories and female nesting sites are established. By June, there were already 16.3 active nests/ha in Fox Grove, indicating that many individuals had their entire reproductive effort for the season committed to the grove. Given this circumstance, it is not surprising that they refused to abandon the grove despite heavy shooting pressure supplemented with scare techniques. Thus each breeding individual had to be shot to remove it from the grove.

Likewise, shooting in groves in the period immediately after breeding (Aug - Sep) required an intensive effort to reduce bird numbers, though damage was held in check by the procedure. We attribute this site tenacity during the post-breeding period to the fact that water is critical during this time, and any site that provides a combination of food, water, and cover in proximity to one another will be readily used by birds despite shooting and cannon pressure. Again, forcing birds out of the groves early in the season provides a good alternative. Failing that, poisoning with DRC-1339 at bait sites near water was successful during this period in some groves (Tipton et al. 1989, this volume).

In contrast to these equivocal results during the breeding and post-breeding periods, it appears that use of pyrotechnics (propane cannons and/or scare shells), offers an excellent deterrant during the winter period. At this time (Oct-Mar), birds forage over several km^2, and readily change their foraging site in response to relatively slight disturbances. A few noisemakers fired in the vicinity of flocks in groves, or even resting in trees near groves is normally sufficient to cause most of the grackles to leave the entire area.

ACKNOWLEDGMENTS

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Fred Guthery, Research Scientist for CKWRI, assisted with the project and the first year data collection and analysis. Nancy Koerth performed statistical analysis. Yolanda de los Santos and Annette Heffelfinger helped with manuscript preparation. David Bergman generated the graphs and tables. And special thanks to Becky Ware Davis, Operations and Public Relations Officer for CKWRI, who kept track of all of us.

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Use of Monofilament Line, Reflective Tape, Beach-Balls, and Pyrotechnics for Controlling Grackle Damage to Citrus[1]

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The effectiveness of monofilament line, reflective tape, beach-balls and pyrotechnics (propane cannons and shotgun scare shells) in reducing damage to citrus by great-tailed grackles was tested in the lower Rio Grande Valley of southern Texas. Results indicate that these treatments can produce reduction in damage. Whether the treatments are economically advisable for a grower depends on the history of grackle damage to the grove and grove size. Only large amounts of damage in large groves justify costs associated with implementation of these methods.

INTRODUCTION

The great-tailed grackle (Quiscalus mexicanus) is a serious pest to the citrus industry of south Texas (Hobbs and Leon 1988). As part of a multi-prong approach to develop techniques to reduce damage to citrus we evaluated a number of non-lethal methods that had been developed for protecting other agricultural crops. Techniques we evaluated were monofilament line, reflective tape (Tobin et al. 1988, Dolbeer et al. 1986), eye spot balloons (Mott 1985, Shirota et al. 1983) and pyrotechnics (Conover 1984). These techniques were evaluated in a series of experiments from 1987 through 1989.

[1] Paper presented at the ninth Great Plains wildlife damage control workshop [Colorado State University, Fort Collins, CO., April 17-20, 1989].

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METHODS

In the spring of 1987, 30 groves of 0.4-ha each were selected to test the effects of reflective tape, monofilament tape, and pyrotechnics (propane cannons and shotgun scare shells) on damage by grackles to citrus fruit. Nine groves (3 replications at 3 different intensities) were used to test each technique, and 3 groves served as untreated plots. Groves were placed into groups of 10 based on their proximity to one another and randomly assigned to the 10 possible treatments. Additionally, all reflective tape and monofilament groves (excluding 1 3-m monofilament grove) had individual control groves located adjacent to them.

Fluorescent yellow monofilament fishing line (9-kg test) was strung in a grid pattern at 1 of 3 different spacings (3-m, 7-m, and 11-m) over 9 groves (3 spacings, 3 groves each). Reflective tape was suspended in rows parallel to tree rows at one of 3 spacings (3-m, 5-m, and 7-m) over 3 groves each. Both the monofilament and scare tape were strung approximately 1-m above the canopy, supported by rows of poles with 1 pole every 30-m. The poles were steel electrical conduit (EMT), 3-m long and 1.3-cm in diameter inserted into a 3-m section of Schedule 40 PVC pipe, 1.9-cm in diameter driven 15-cm into the ground. The height of the poles was adjusted for each grove by sliding the EMT section within the PVC section to the desired height, and securing it by drilling a hole through the EMT just above the PVC and inserting a nail. Each pole was supported by guylines running to 3 wooden

stakes. Poles, stakes, and guylines were all located within the dripline of the trees so as not to interfere with normal grove operations.

In the monofilament groves, Size 24 nylon twine was run from top to top of the poles around the perimeter of the grove, and also across the tops of each row of poles within the grove. In the groves treated with reflective tape, nylon twine was run only across the tops of each row of poles within the grove. The monofilament and reflective tape were then connected to the nylon twine at the desired spacing. Monofilament was attached directly to the twine. Reflective tape was wrapped around wooden dowels, which were then attached to the nylon twine with duct tape.

Propane cannons (Margo Supplies Ltd., Calgary, Canada) were placed in 9 groves of 0.4-ha each in 1987. The cannons are metal tubes roughly 1-m in length that stand about 1-m off the ground on a tripod. They are connected to a 10-kg propane tank. A timed, electronic spark ignites a small amount of propane at pre-set intervals producing a loud, "thunderclap" sound of 80-120 decibels. Three different treatments were applied: 1) 3 groves had single detonation cannons placed in one corner of the grove and pointed toward the diagonally facing corner, 2) 3 groves received 1 multi-detonation cannon on rotomats (cannon placed on 360 degree rotating platform) placed in the center of the grove, and 3) 3 groves had both a multi-detonation and a single detonation cannon placed as described in Treatments 1# and #2 supplemented by firing of "Shot Tell scare shells (Reed Joseph International Co., Greenville, Mississippi) over the treated grove 4 times daily. These scare shells are fired from a 12 gauge shotgun. They explode with a very loud noise at about 50-m down range. Cannons in all treatment groves were turned on in the morning shortly after daylight and off in the evenings before nightfall. These treatments were applied daily from 1 June - 1 September 1987.

In the spring of 1988, two additional series of nonlethal experiments were initiated. Results from the 1987 monofilament-grid experiments indicated that 3-m spacing did reduce damage but was not cost effective because damage levels in the treated groves were not high enough to justify the treatment. Three citrus groves with histories of high damage levels have been selected to revaluate monofilament line placed at 3-m intervals. Control areas were set up adjacent to the treatment plots within the same groves. Two of the groves had been used as control groves in the 1987 monofilament study allowing for temporal comparsion between years. Method for hanging the line was similar to the 1987 study.

Preliminary tests with eyespot balloons (Avery et al. 1988) indicate that this procedure might be effective, especially in urban areas where noisy or lethal techniques might not be accepted. Four groves were chosen for treatment using eyespot balloons. It was determined that commercial eyespot balloons would be cost prohibitive, so beach-balls, 51 cm in diameter, were used. The balls were placed at the end of guyed poles extending 1 m above the canopy in selected groves at densities of 1 beach-ball /10 trees(3 groves) and 1 beach-ball/4 trees (1 grove). For 3 groves, the beach-balls were painted white with 3 large black irises and bright red pupils, and in 1 grove the beach-balls were used as purchased (i.e. multicolored - red, blue, green, yellow). Each 0.4-ha treated area was paired with a 0.4-ha control area adjacent to the treatment area.

Damage was assessed in the 1987 studies by selecting 10 randomly selected trees/grove before initial fruit harvest in the fall of 1987. All fruits on the sample trees were classified as undamaged or damaged by birds. Damaged fruit was further graded using a modified USDA grading scale for grapefruits (Johnson et al. 1989). Grades 1-3 represent fresh (<25% of fruit damaged by birds), juice fruit (>25% of fruit damaged by birds) and unusable fruit, respectively.

For the evaluation of control procedures used in 1988 groves were chosen that had a known history of high damage or were part of our damage assessment program for 1987. Damage was assessed for 1988 experiments by randomly selecting 15 trees/grove and evaluating damage on a monthly basis starting in June. Procedures and time intervals were as followed in 1987 (Johnson et al 1989).

RESULTS AND DISCUSSION

Reflective tape was considered an impractical method for use in reducing grackle damage to citrus in the Rio Grande Valley. As a result of the high daily winds (> 25 km/h) during the test period, the scare tape was consistently breaking at connection points or becoming entangled in the trees and breaking at the point of entanglement. The majority of the tape did not stay suspended for longer than 2 weeks before replacement was necessary.

In an effort to try to develop an attachment technique that would increase the suspension life of the tape, tests were conducted in Kingsville with many attachment methods. All of the tested attachment methods failed to keep the tape suspended for longer than 2.5 weeks. After tests with different methods failed to yield a satisfactory attachment, evaluation of reflective tape was ended.

Results from tests of the effectiveness of pyrotechnics in reducing grackle damage to citrus proved inconclusive. Although there were no significant differences between the various levels of intensity or between treated and untreated groves, it was not possible to determine if differences in damage levels between treatment and control groves and between treatments were due to treatment or location differences.

Monofilament groves in the 1987 treatments had less damage than the mean damage of the 3 test plots. Damage was 0.37, 0.86, and 2.7% lower in the 7, 3, and 11-m groves, respectively, thus indicating that the 11-m spacing afforded the most protection. When treatments are compared to their individual controls ("next-door-neighbor" comparisions), however, the results are very different (table 1). We feel that comparisons with individual controls more accurately measure the effectiveness of the technique because damage tends to be site-specific and differences in damage may be due to location and not treatment. In these

Table 1.—Effects of monofilament on damage rates to citrus fruits in October 1987.

	Mean Damage % in October	
Grove	Treatment	Control
Block 1		
3-m	3.48	7.27
7-m	4.22	7.94
11-m	0.56	0.58
Block 2		
3-m	3.71	15.95
7-m	5.96	13.94
11-m	2.61	8.08
Block 3		
3-m	2.07	
7-m	0.70	3.04
11-m	0.69	0.96

comparisons treatments reduced bird damage an average of 1.95, 4.68, and 8.02% for the 11, 7, and 3-m spacings, respectively.

Monofilament groves for the 1988 treatments had lower damage levels (table 2) for all groves and all months. Since all 3 groves used 3-m spacing, data were combined and a paired t-test was run to compare treated vs untreated groves. The resulting p value was 0.249.

The eye-spot groves in the 1988 treatments also had less damage (table 3). Data for all groves was combined for the analysis. Results from a paired t-test was (p= 0.0535).

Table 2.—Effects of monofilament on damage rates to citrus fruits in 1988.

Grove	Mean Damage % by Month			
	Jul	Aug	Sep	Oct
Val Verde - T[1]	1.7	4.3	3.0	3.5
Val Verde - C[2]	3.0	5.4	4.6	4.4
Anderson - T	0.9	3.0	2.1	2.9
Anderson - C	1.0	4.2	4.1	3.3
Van Meter - T	0.6	2.0	1.6	2.1
Van Meter - C	3.8	5.1	5.3	5.9

[1]T = Treatment (monofilament).
[2]C = Control (no monofilament).

Table 3.—Effects of eyespot balloons on damage rates to citrus fruits.

Grove	Mean damage % by Month			
	Jul	Aug	Sep	Oct
Segrado - T[1]	0.2	1.9	1.2	1.6
Segrado - C[2]	0.9	2.2	3.4	2.6
Dillon - T	2.9	7.4	5.2	7.2
Dillon - C	8.1	12.4	10.1	8.2
Romain Site 1 - T	2.0	4.8	3.0	3.0
Romain Site 1 - C	6.6	9.8	6.6	6.6
Romain Site 2 - T	2.2	6.9	3.7	4.6
Romain Site 2 - C	6.6	9.8	6.6	6.6

[1]T = Treatment (eyespot balloons).
[2]C = Control (no eyespot balloons).

CONCLUSIONS

Grackle damage appears highly variable from 1 site to the next so tests need to be conducted which take this variability into account.

Reflective scare tape is not a viable technique for reducing grackle damage to citrus due to prevailing winds in south Texas. Pyrotechnics are not effective when used a the only method of reducing damage. Propane cannons and scare shells can be used effectively in the fall and early winter when birds are moving from grove to grove on a daily basis. Pyrotechnics are also effective if reinforced with live ammunition. Monofilament line and eyespot balloons all hold some promise in terms of damage reduction. Every grove in which these techniques were used showed lower damage levels than untreated groves. Damage levels in groves in 1988 was in general was lower than in 1987. This reduced damage level and the small sample size could have contributed to the lack of statistical significance.

Cost benefit analysis is presently being conducted to determine if these techniques would be cost effective. Preliminary results indicate damage levels must be very high to justify the use of monofilament line.

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Effects of Grackle Damage Control Techniques in Citrus on Nesting Success of Non-Target Species[1]

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Several techniques were tested to reduce the damage caused by great-tailed grackles to citrus in the lower Rio Grande Valley of southern Texas: monofilament line, eyespot balloons, pyrotechnics, and grackle nest removal. Ten species were found nesting in the treated groves, but only the mourning dove, white-winged dove, and great-tailed grackle in significant numbers. Nesting success was not reduced significantly by any treatment but observations indicate that cannon treatments are likely to have a negative impact on overall nesting success for several species.

INTRODUCTION

Mature citrus groves provide suitable nesting habitat for great-tailed grackles in the lower Rio Grand Valley of southern Texas. Densities > 20 nests/ha were found in 20% of the groves examined during our study. Typically, these groves contain large trees and an ample water supply (irrigation ditches). Also they are usually located near fallow fields that provide a source of Lepidoptera larvae for hatchlings. High nesting densities of grackles are directly correlated with high damage rates to citrus fruit in the groves (Rappole et al. 1989, this volume). Therefore, several control techniques have been tested to reduce the number of grackles nesting in groves with high nesting densities.

In addition to grackles, several other avian species nest in citrus groves including the economically valuable white-winged dove (Zenaida asiatica). This species is estimated to bring 20 million dollars annually to the Rio Grande Valley economy during the 2 weekend/yr hunting season in September (George 1985). In this study, we surveyed citrus to identify what species other than grackles nest in the groves, and we assessed the possible effects of various grackle control techniques on the nesting success of these birds.

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METHODS

Citrus groves were selected at random from a pool of available groves in 1987 to test the effects of reflective tape (scare tape), monofilament line, and pyrotechnics (propane cannons and shotgun scare shells) on damage by grackles to citrus fruit. Nine groves (3 replications at 3 different intensities) 0.4-ha in size were used to test each technique. Groves with monofilament and reflective tape were split into 0.4-ha treatment and control sections.

In 1988, we re-tested techniques that appeared to show some promise in reducing grackle damage to citrus fruit from our 1987 work; and we tested a new technique, eyespot balloons. In testing these techniques, groves known to have had high grackle nesting densities were used, rather than a random sample as in 1987.

Fluorescent yellow monofilament fishing line (20-lb test) was strung in a grid pattern at 1 of 3 spacings (3, 7, and 11-m). The scare tape was used at spacings of 3, 5, and 7-m. Details of these methods are presented in Tipton et al. (1989, this volume). All treatments were put in place during the first 2 weeks of June, 1987 and continued until August 1987.

The pyrotechnics were used in 3 different configurations: 1) 1 single detonation cannon/0.4-ha firing once every 2-5 minutes throughout daylight hours, 2) 1 double detonation cannon/0.4-ha firing every 2-5-min during the day, and 3) 1 double detonation cannon/0.4-ha firing every 2-5-min supplemented with firing of "Shot Tell" scare shells (12-ga shotgun shells that fire an explosive charge roughly 50-m down range) discharged 4 times/day over the grove.

Six additional groves were selected for treatment with cannons alone (2 double detonation propane cannons/0.4-ha) in groves that were known to have high whitewing nesting densities. Treatments were begun during the first 2 weeks of June, 1987 and continued through July 1987. Only whitewing nests were recorded and

tracked in these groves.

Monofilament was tested again during the summer of 1988 when it was installed in early April in 3 groves of 0.4-ha each at a 3-m density using procedures described in Tipton et al. (1989, this volume).

Beach-balls, 51-cm in diameter, were placed in 4 groves during the 1988 season to reduce damage to citrus fruit. These balls were placed at the end of guyed poles extending 1-m above the canopy in selected groves in March, 1988 at a density of 1 beach-ball/10 trees. For 3 groves, the beach-balls were painted white with a large black iris and bright red pupil, and in one grove the beach-balls were used as purchased (i.e. multicolored - red, blue, green, yellow). Each 0.4-ha treated area was paired with a 0.4-ha control area.

In addition to these passive treatments, we instituted a grackle nest removal treatment 1 in 2 groves from March - June 1988. The groves were 0.3 and 0.8-ha in size. In each grove, all grackle nests were removed by pulling them down using a long pole with a hooked end on a bi-weekly basis.

In each of the treated groves, every citrus tree within the grove was given a number (there are roughly 200 trees in a 0.4-ha grove). Each tree within the grove was checked weekly for grackle nests and for the nests of non-target species from 25 June - 15 August, 1987 and from 28 April - 17 June, 1988. For each nest located, the species, date, tree number, and status (number of eggs and/or young, age of young) was recorded, and the tree was marked with a strip of red engineers tape. All nests were re-visitec and their status recorded weekly until the young fledged or they were destroyed by predators. The number of eggs laid was compared with the number of young fledged to obtain a percent hatching success for each treatment.

Only the mourning dove (Zenaida macroura) nested in sufficient densities to allow statistical comparison of the effects of treatments on nesting success for most of the treatments. Analyses compared mean percent fledging success (total young fledged/total eggs laid) for each set of treatments (monofilament, reflective tape, eyespot balloons) with paired control groves using a paired t test. The fledging success in nest removal and pyrotechnic groves was compared with that of control groves from the monofilament, reflective tape and eyespot groves for their respective years using a 2 sample t test.

White-winged doves nested in low densities within the randomly selected groves, but were found in good densities in a few non-randomly selected groves, which were used in testing the effects of cannons on whitewing nesting success. The control groves used for comparison with these treated groves were surveyed by Texas Parks and Wildlife Department as reported by Waggerman (1988). A 2 sample t test was used to compare treatment versus control nesting success.

RESULTS AND DISCUSSION

Thiry-six 0.4-ha groves (14.4-ha) were examined for nests in 1987 out of the 48 total groves in the experimental design (excluding the whitewing groves). The remaining groves were missed due to a variety of problems including heavy rainfall, flooding for irrigation, jet-spraying with pesticides, and high winds causing collapse of reflective tape treatments. A total of 14 groves (5.9-ha) was examined for nests in 1988, 12 groves of 0.4-ha each, and 2 odd-size groves of 0.3 and 0.8-ha respectively.

Ten species of birds were found nesting in treatment and control groves during 1987 and 1988 (table 1), 5 in 1987 and 10 in 1988. Mourning doves were the most numerous species in the groves, and were relatively evenly distributed as well, occurring in 30 of 42 groves examined in 1987 and 14 of 14 groves in 1988. Clearly, citrus is a very important component of mourning dove reproduction in the Rio Grande Valley, providing nesting habitat for an estimated 50,000-300,000 pairs. The lower nesting pair density estimates (1987) given in table 1 are probably more accurate as they are based on densities in groves that were randomly selected rather than on groves known to have high grackle nesting densities, as the 1988 samples were.

Table 1.--Total nests and nest densities for species found in citrus groves treated to reduce grackle damage during the 1987 and 1988 breeding seasons.[1]

Species	Total Nests		[2]Nests/ha		[3]Est. pop. (x1,000)	
	1987	1988	1987	1988	1987	1988
White-winged Dove Zenaida asiatica	5	4	0.3	0.7	3.5	8.2
Mourning Dove Zenaida macroura	77	105	5.3	17.8	62.3	209.0
Inca Dove Columbina inca	1	3	0.1	0.5	1.2	5.9
Common Ground-Dove Columbina passerina	0	3	0.0	0.5	0.0	5.9
White-tipped Dove Leptotila verreauxi	2	3	0.1	0.5	1.2	5.9
Yellow-billed Cuckoo Coccyzus americanus	2	3	0.1	0.5	1.2	5.9
Common Pauraque Nyctidromus albicollis	0	3	0.0	0.5	0.0	5.9
Northern Mockingbird Mimus polyglottos	0	1	0.0	0.2	0.0	2.4
Long-billed Thrasher Toxostoma longirostre	0	2	0.0	0.3	0.0	3.5
Great-tailed Grackle Quiscalus mexicanus	41	17	2.8	2.9	32.9	34.1

[1]Excludes 1987 whitewing groves.

[2]A total of 16.8-ha (42 groves of 0.4-ha each) was examined in 1987 and 5.9-ha (14 groves of 0.4-ha each) in 1988.

[3]Total pairs of birds nesting in citrus based on estimated citrus acreage of 11,760-ha for the entire lower Rio Grande Valley.

Nesting densities for white-winged doves were far below expected values. Texas Parks and Wildlife Department conducts spring counts based on numbers of calling birds which are then used to estimate breeding population sizes in citrus and chaparral habitats (Rappole and Waggerman 1986). The estimates of nesting densities in citrus were 4.5 pairs/ha for 1987 and 5.1 pairs/ha in

1988 (Waggerman 1988), different by a factor of 10 from our estimates. It should be noted that our groves were located in the east and central portions of the Valley, and that there are groves in the northwest portion where nesting densities are as high as 50 pairs/ha. However, the number and area of these groves is a small percentage of the total 11,760-ha of citrus in the Valley, making us worry that whitewing numbers are currently being over-estimated by a considerable amount. Accurate estimates of whitewing numbers are critical for establishment of proper bag limits for the hunting season.

Reflective tape treatments appeared to have no effect on nesting success for mourning doves (table 2). This result conforms with field observations in which we observed mourning doves and grackles entering groves treated with the tape without any apparent reaction to tape presence. In addition, the tape on these groves was often down because it breaks easily in the strong southeasterly winds (26-32-km/h) that prevail throughout the summer in the Valley.

Table 2.--Mourning dove nesting success (%) for 1988 in groves with monofilament, eyespot balloons, or nest destruction as compared with control groves.

Treatment	Number of groves	Total eggs laid	Mean % nest success	Standard Deviation
Nest destruction	2	43	27.5	23.3
Monofilament	3	33	63.3	32.1
Monofilament control	3	34	53.0	12.7
Eyespot	3	38	47.0	12.1
Eyespot control	3	27	62.0	33.6

Results from the eyespot and monofilament treatments similarly produced no significant reduction in nesting success in mourning doves (tables 2 and 3). Field obseravations were consistent with this result, as we observed no avoidance behavior toward the fishing line or beach balls by birds entering or leaving the groves. However, a great-horned owl (Bubo virginianus) was killed in a collision with one of the monofilament lines.

The lack of any statistically significant reduction in nesting success by the pyrotechnic treatments for whitewings (table 4) and mourning doves (tables 2 and 3) was surprising to us. The effect of the cannons on birds nesting in cannon-treated groves was obvious to the observer, causing the incubating or brooding bird to fly off the nest in many cases, particularly for those located within 50-m of the cannon. The high variance and small size of the samples are the probable explanation for the lack of a statistically significant result. The effects of pyrotechnic techniques on nesting success of non-target species should receive further study if these are to be considered for widespread use.

A similar situation occurred with the statistical evaluation of the effects of grackle nest removal on non-target species. Only 2 groves received this treatment, Nonmacher and Signez, and the statistical analysis showed no significant reduction in nesting success as compared with controls. The Nonmacher grove was 0.8-ha in size. This grove had moderate grackle densities, and mourning dove nesting success was 45.4%. The Signez grove was 0.3-ha and only 2 of 21 eggs laid produced fledged young (9.5%). Grackle density in Signez was very high, despite the removal of their nests, and the effect of the personnel pulling nests down was to frighten incubating or brooding birds of non-target species off from their nests exposing the contents to grackle predation.

Table 3.--Mourning dove nesting success (%) for 1987 in groves with monofilament, reflective scare tape, or pyrotechnics as compared with control groves.

Treatment	Number of groves	Total eggs laid	Mean % nest success	Standard Deviation
Monofilament	8	20	21.4	35.6
Monofilament control	8	16	40.3	41.6
Reflective tape	9	15	31.4	40.9
Reflective tape control	9	3	20.8	35.4
Pyrotechnics	8	53	22.6	34.0

Table 4.--Whitewing nesting success (%) for 1987 in citrus groves containing propane cannons.

Treatment	Number of groves	Total eggs laid	Mean %nest success	Standard Deviation
Cannons	6	100	28.5	19.4
Control	3	109	40.0	15.9

CONCLUSIONS

Citrus provides important nesting habitat for at least 10 species of birds native to the lower Rio Grande Valley of Texas. Refelective scare tape, monofilament, and eyespot balloon treatments placed in the groves do not appear to have negative effects on nesting densities of these species. Propane cannons and bi-weekly destruction of grackle nests may have negative effects, and need to be tested further if their use is expanded for protecting groves from grackles. Populations of white-winged doves nesting in citrus appear to be seriously over-estimated by procedures currently used by Texas Parks and Wildlife Department. Further work should be done to develop accurate techniques for assessing breeding population size of this important game species.

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Use of DRC-1339 and PA-14 to Control Grackle Populations in the Lower Rio Grande Valley[1]

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In an attempt to reduce valley wide populations of grackles in the Rio Grande Valley of South Texas, PA-14 was sprayed over a staging area where as many as 10,000 birds were located. This attempt was unsuccessful and this method of population reduction was deemed not suitable for south Texas. Dog food bait was treated with DRC-1339 and presented to great-tailed grackles in several different situations in an attempt to control depredations to citrus by this bird. Bait presented in feedlots during winter (Nov - Feb) was readily taken by the birds, resulting in a significant reduction of numbers of birds visiting these sites, but with little apparent effect on the valley-wide population or damage to citrus. Baiting at pre- and post-roost staging sites was not effective, even when supplemented with decoys. Baiting at nest colony sites early in the breeding season (Apr - May), and at water sources during the post-breeding period (Jul - Aug) were effective in reducing damage locally.

INTRODUCTION

As part of a multi-prong approach to reducing great-tailed grackle (Quiscalus mexicanus) damage to citrus in the Rio Grande Valley of southern Texas, we attempted to develop methods to eliminate large numbers of birds, thereby reducing the Valley-wide population. Large numbers of grackles (> 500,000 in late winter) were known to roost in sugar cane fields from September to March. During this period grackles also tend to congregate in large numbers (>10,000 individuals) at staging areas prior to entering roost sites. Previous research (Heisterberg et al. 1988) has documented that large numbers of roosting birds can be killed using the avian stressing agent, PA-14 [a-Alkyl (C11-C15)-omega-hydroxypoly (oxyethylene)]. We investigated the dispensing of this material on the grackles by spraying it from an aircraft (Cessna 150 equipped with crop duster chemical tanks). When evaluating this technique we also considered the environmental and sociological hazards posed by the technique against the probability of successfully eliminating a large portion of the grackle population (Otis 1988).

Other studies (Boyd and Hall 1988) have documented success in eliminating large numbers of birds using toxic baits, specifically DRC-1339 (3-Chloro-p-toluidine hydrochloride). These studies were conducted at staging areas and roost sites of crows in Kentucky and Arkansas.

Habitat studies (Rappole et al. 1989 this volume) and previous control efforts indicate that in addition to roost sites and staging areas, large numbers of grackles feed in graineries, cattle feedlots and dairies during the winter months (Oct - March).

Results from feeding trials conducted at Texas A&I in 1987 indicated that grackles preferred dog food over most naturally occurring foods (Beasom and Schulz, in prep.). Preliminary observations have shown that this form of delivery is relatively specific to grackles with minimum acceptance by other species (unpublished data). An Experimental Use Permit was established to use DRC-1339 applied on dog food to be used in staging areas, dairies, and feedlots. In addition, attempts were made to bait birds into other situations, along flight lines, at watering holes, and at breeding colonies to determine if DRC-1339 would be effective in eliminating birds and reducing damage in local areas of high damage.

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METHODS

Grackle Population Reduction Using PA-14

During the winter months (Dec - Feb), great-tailed grackles concentrate in large winter roosts, especially in mature sugar cane fields. The sugar cane is cut through the fall and winter, progressively reducing the amount of cane available for roosting. Those birds roosting in fields that are cut tend to join birds flying to roost sites in uncut fields. As a result, by late January, when few uncut fields remain, a large portion of the grackles in the Valley may roost at a single site. This situation occurred in January and February of 1987 when an estimated 500,000 grackles, roughly 1/2 to 2/3 of the entire Valley grackle population, were roosting in a single 14-ha field of mature sugar cane just south of Donna Reservoir, Donna, Texas. For this situation, we considered using the wetting agent, PA-14, to kill birds in the roost. PA-14 is a surfactant that enhances wetting of birds when sprayed in combination with a rain shower or with water dispersed from sprinklers. The combination of water, the PA-14 wetting agent, and low ambient temperatures (< 7 C) can cause death due to hypothermia in passerines. This plan was rejected because we were informed that it is illegal to use PA-14 on crops grown for human consumption. A further problem involved the proximity of the site to Donna Reservoir. It is illegal to use PA-14 near a human water supply, and the material is toxic to many aquatic life forms.

We next considered using the material on birds that were "staging". This "staging" behavior occurs as the birds approach the roost at night and again when they leave in the morning. Large numbers of birds entering or leaving the roost land at a site, forming an almost solid mass of individuals before entering the roost (evening) or dispersing to feeding sites. Staging areas at the Donna Roost were bare dirt fields where as many as 10,000 birds would alight in an area 100-m in diameter.

Grackle Population Reduction using DRC-1339

DRC-1339 at Dairies

DRC-1339 treated dog food was dispensed at Miller dairy in Hidalgo County, Texas on four seperate occassions between January 1988 and February 1988. The selected dairy was in the flight line of a major roost (>100,000 near Donna, Texas). We applied DRC-1339 to "High-Pro" dog food, identified in earlier research (Schulz and Beasom 1989 in Prep.) as preferred bait. The starlicide label calls for a mixture of 45-g of DRC-1339 to 600-ml of water for 4.5-kg of bait. We doubled the mixture to coat 9-kg of dog food. The bait was coated with DRC-1339 1 day in advance of dispersal, allowed to dry and stored in 5-gallon buckets. A crude volumetric analysis was done to determine how much poison was contained in each pellet. Based on this analysis we estimated 2.75-mg/pellet. This would be 15 times more poison then needed to kill 50% of female grackles and 9 times more then needed for males, based on an LD_{50} of 1.8-mg/kg. Although the formulation of the chemical they used was slightly different, they found the LD_{50} in boat-tailed grackles (Quiscalus major) to be from <1.00 - 1.8-mg/kg. In our analysis we used 100-g for weight of females and 164-g for males. In some simple pen studies we determined that 1 pellet did contain enough poison to give an LD_{100}. We therefore believe it would be possible to reduce the concentration of the posion by at least 50%.

To minimize the possibilities of leaving poisoned bait at the dairy, attempts were made to attract animals by placing bait in large trays (236 x 114 x 13-cm) on the ground. The birds were not attracted to the bait presented in this manner. Nor were the birds attracted to bait placed on large pieces of 0.6-cm mesh screen covered with sifted soil. Finally, we spread the treated dog food on the ground in empty cattle holding pens before daylight. About 20-kg of food was used for each days treatment.

Flight line counts over the dairy were made for at least 3 days prior to and 3 days after baiting. Untreated dog food was spread in the holding pens prior to counts. In February, seperate counts were made of birds flying over the pens and of birds landing in the pens to determine if flight counts and pen counts were correlated.

DRC-1339 Along Flight Lines

Decoys were tested for attracting for baiting with DRC-1339 between 1 March 1988 and 15 March 1988. The area around Donna roost was selected because of a consistent northerly flight line leaving the roost each morning. Three types of decoys were tested on 3 seperate occasions: 1) black poster board silhouettes with horzontal wings, 2) black poster board silhouttes with horizontal wings and tails, and 3) 5 x 8 x 10-cm blocks of black foam. The silhouettes were placed on sticks and inserted in the ground to simulate grackles feeding. The foam blocks were placed directly on the ground. In the first test, we used 27 silhouette decoys with wings. In the second test we used 27 silhouette decoys with wings and tails. In the third experiment we used 12 foam block decoys and a moderate amount of corn scattered around the decoys. Decoys were placed 15 minutes before dawn. Counts of birds landing near the decoys were taken 40-min after the first bird left the roost.

Attempts were again made in the fall of 1988 to attract birds to bait sites. Plastic crow decoys were used in conjunction with milo, cracked and whole corn bait applied in staging areas from 13-26 October. James Glahn, Research Scientist for Denver Wildlife Research Center, helped conduct baiting experiments in December of 1988. On December 7 and 8, 3 staging sites near the Eldora roost were baited with 23-kg of cracked corn and 11-kg of dog food. Eight to 16 live decoys in cages were also used at each site. On December 9-11, 4 bait stations were established near Donna Reservoir roost site. Live and dead decoys were used at each site along with whole corn and dog food.

DRC-1339 at Citrus Groves

Beginning in the spring of 1988 and continuing through July 1988, we used DRC-1339 coated dog food in 5 selected groves. Based on our earlier pen studies we reduced the label-specified concentration of DRC-1339 by 50%.

These groves were selected because they had nesting grackles, histories of high fruit damage and some available source of water. Preliminary trials indicated that baiting near a source of water greatly increased the effectiveness of baiting. The water available to the grackles differed at each site. Three different sources of water were chosen for evaluation: constant source, water pans, and artificial pools.

Although the sources of water varied, the pre-baiting and baiting procedures were the same in each grove. Sites were pre-baited until at least 25% of the birds in the groves were coming to the stations in a 1h period. Decoys were also placed at some bait stations.

Bait stations were observed for 1h each morning and the number of grackles eating the dog food was recorded. Counts were made for at least 3 days post-poisoning.

To evaluate the effect of this technique in reducing damage to citrus, damage assessment to the groves were also conducted. Counts of damaged and undamaged fruits were made on a monthly basis on 15 randomly selected trees. Damage in 1 grove (England's) was compared with results of damage assesment from 1987. Damage for the other groves were compared with pre-treatment levels. Timing and method of evaluation of damage was detailed in (Johnson et al. 1989).

Constant Source of Water

One grove (England's grove) was chosen for its constant source of water in the form of a cattle pond (18.3 x 3.0-m) located in the middle of the grove. The grove consisted of 2.8-ha of grapefruit and 2.8-ha of oranges. Counts were made in this grove from April - November, 1988 with poisoning occurring 3 times (26 May, 18 Jul, and 5 Aug).

Water Pans and Artificial ponds

Four groves with nesting grackles and observed grackle damage were selected for artificial water devices. Water pans (236 x 114 x 13-cm) were placed in each treatment grove. Two of these sites failed to attract birds in the pre-baiting period probably because of nearby competing water sources. These groves were abandoned. Two sites were selected in Rio Farms (A and D) and 2 sites in Santa Rosa (N and S). Water pans were used in the 2 sites in Rio Farms and site S in Santa Rosa grove. For the N site in Santa Rosa an irrigation valve was cracked open and a small pool of water (4 x 2-m) was allowed to form. Dog food was scattered around the pans and at the edge of the pool. When good pre-bait acceptance was observed (75-100% pre-bait taken in 4h period) treated bait was set out. Counts were made by recording the number of birds feeding at the pans for 30 min after the first grackle arrived.

RESULTS AND DISCUSSION

Grackle Population Reduction Using PA-14

We obtained permission to use PA-14 on staging areas during the winter of 1987-88, and attempted to spray birds from an aircraft on the evening of 15 January 1988. This evening was selected because it provided the only suitable meterological conditions for PA-14 during that entire winter. Temperatures were 5 C with a light to moderate rainfall. These conditions are very rare in the Valley, occurring only once or twice a year. The attempt was unsuccessful in any case because the birds scattered as soon as the plane began its low level spraying run. Previous flights over birds roosting in sugar cane indicated that their flight behavior was such that spraying PA-14 could have been effective. This technique might still prove effective if permission could be obtained to spray the birds while roosting in sugar cane. The number of birds in the cane fields might justify the risk and expense of finding the right environmental conditions. With the present restrictions we have to conclude that this method of control is not suitable for south Texas.

Grackle Population Reduction using DRC-1339

DRC-1339 at Dairies

After the initial poisoning at Miller dairy, 43 dead grackles were recovered. Post-counts were not made until 3 days after treatment at which time more birds were flying over than when we poisoned. After the second poisoning, 1,206 dead birds were found. Females outnumbered males 10:1. Post treatment flight line counts dropped dramatically but numbers recovered in about 15 days (fig. 1). After the third poisoning, 31 birds were recovered. Post-count numbers dropped only on the first day after poisoning. Fifty-four birds were recovered after the fourth poisoning. Flight line numbers briefly decreased as in previous trials.

The number of birds landing in the holding pens, as might be expected, was always lower than the number flying over. The response in the pens paralleled the response in the flight lines.

Since dairies attract large numbers of birds in the morning, they represent potential large natural bait stations. However, baiting at dairies was not effective in reducing local populations. The number of birds flying over the dairies differed by only 1,050 birds throughout the study period. The dairy population recovered 2 - 15 days after poisoning.

Only on 1 occasion were we able to recover a large number of birds. The newness of the bait, variable weather conditions or some undetermined factor may have affected our efforts. Because DRC-1339 may take up to 18 hours to kill the birds, the number of dead birds recovered does not reflect the number that may have actually been killed. Most of the dead birds were found along canals and/or in thick grass while large numbers could have died in sugar cane roost sites or other unaccessible areas.

DRC-1339 Along Flight Lines

Attempts to decoy birds into staging areas in spring were not very successful. Using silhouettes with wings, only 28 birds landed near the decoys although hundreds of birds flew over the test site. Using silhouettes with wings and tails , 131 birds landed. The foam block decoys were the least effective with less then 10 birds landing and about 200 birds flying over. The best results were obtained using silhouette decoys with horizontal wings and tails, however the percentage of birds landing was very low regardless of the type decoy used. This method was therefore deemed inadequate for local population reduction.

Results of baiting and decoys in fall of 1988 also left some doubts as to the value of this technique. Only 12 birds were decoyed by the caged birds and bait at the sites near the Eldora

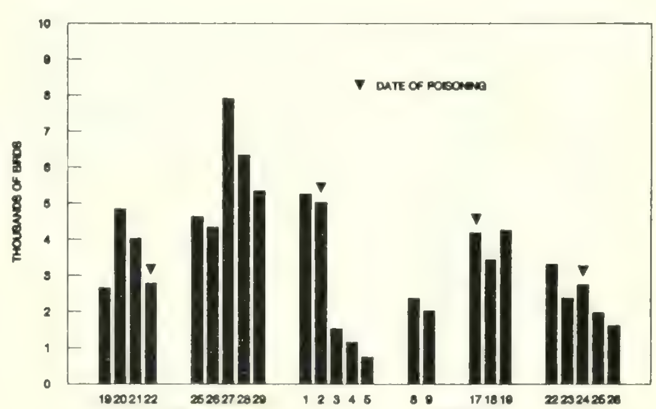

Figure 1.—Grackle use of Miller Dairy.

roost. At one of the sites near Donna Reservoir large numbers of birds fed for about 15 minutes each evening before they entered the roost. The other 3 sites were not used by birds.

DRC-1339 at Citrus Groves

Populations coming to the bait stations in the groves usually dropped immediately after poisoning (fig. 2-5). Populations returned to pre-bait levels within 2 weeks to 1 month after poisoning. Damage to fruit in the groves was reduced in England's grove when compared with damage levels from 1987 (table 1). Damage levels in the other groves remained low except in the Santa Rosa N site.

Table 1.—Effects of DRC-1339 on damage rates to citrus fruit.

Grove	Year	Mean damage % by month			
		Jul	Aug	Sep	Oct
England - T	1988	5.5	5.2	12.6	4.4
England - C (temporal pair)	1987	1.9	6.6	17.8	14.6
Santa Rosa Site N	1988	2.9	2.7	4.1	9.4
Santa Rosa Site S	1988	8.8	8.9	21.4	31.6
Rio Farm Block A	1988	6.0	5.2	3.1	5.8
Rio Farm Block D	1988	0.8	0.6	0.4	1.4

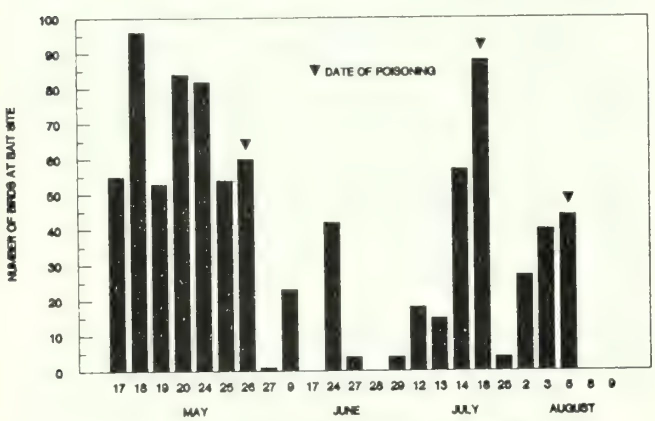

FIGURE 2.—Grackle use of England's Grove.

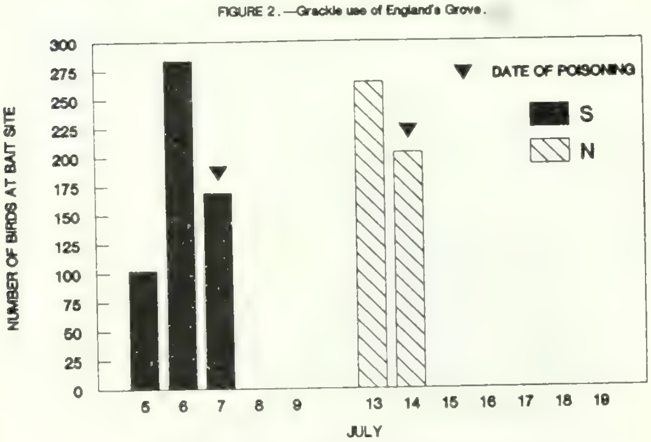

Figure 3.—Grackle use of Santa Rosa N and S.

The individual characteristics of the groves determined the success of the baiting program. Groves with canals and or sorghum fields nearby had poor results in attracting birds. For example, in an 3.2-ha grove with a canal and sorghum field nearby, less than 10 birds from a population of approximately 200 during the peak of the nesting season were enticed to the bait stations in a 3 month period.

However bait stations used in areas with artificial water sources or small pounds were successful in attracting birds and reducing damage.

CONCLUSIONS

Contrary to results obtained in control efforts in other parts of the country, the solution to the grackle problem in south Texas does not seem to lie in techniques aimed at eliminating large number of birds to reduce the Valley-wide population.

Use of the PA-14 wetting agent is not a viable alternative in the Valley for several reasons. A high human population along with extensive agricultural and residential development limits the number of places where the method could be used. Weather in the Valley is normally warmer and dryer than is necessary for the method to work, with the exception of perhaps 1 or 2 nights during the entire year. In addition, the behavior of the birds is such that the only place where they are vulnerable to spraying is when they are on the roost, after dark. Since roosts are normally located in sugar cane or near water, they are not suitable for application of

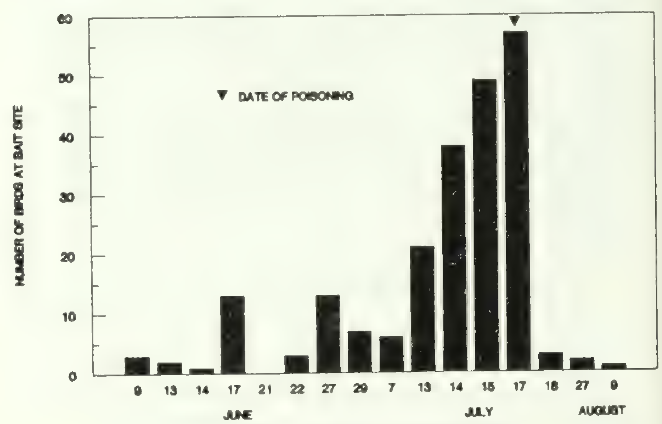

Figure 4.—Grackle use of Rio Farms Block D.

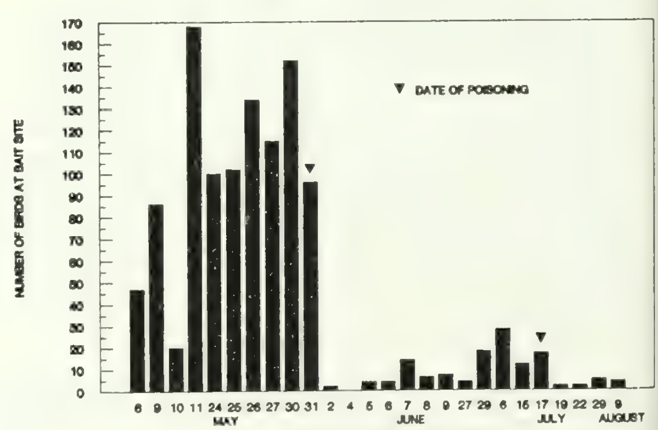

Figure 5.—Grackle use of Rio Farms Block A.

this poison with present restrictions. Even if all of these problems could be solved, it is unlikely that killing grackles with PA-14 or DRC-1339 at central collection points, e.g. roosts or feedlots during the winter, would reduce damage to citrus in summer and fall. Reduction of damage would require a significant reduction in the entire Valley-wide population, since birds at this time forage over several km^2 and fly as far as 10-km to roost. This process would require killing several hundred thousand birds. Such a reduction, even if achievable, is unlikely to be cost-effective. Control at this time is best directed specifically at groves that are experiencing significant damage to fruit by grackles, rather than wasting resources on the Valley-wide population of grackles, most of which are not involved in causing the damage.

The environmental conditions around citrus groves and the seasonal acceptance of bait, dictate the success of using DRC-1339 in groves or nesting colonies. For groves with no source of continuous water near the grove, the use of DRC-1339 coated dog food with a water source offers a viable technique to reduce grackle populations in groves that suffer damage during and immediately following the breeding season (May - Aug) when the birds will remain in the groves. Proposed research for the 1989 growing season will be directed toward establishing bait stations in groves with high levels of nesting grackles or in groves near nesting colonies. Baiting will be started earlier (Apr - May) than in 1988, before the nesting birds become established in the groves. Birds that survive the poisoning will be eliminated with shotguns to try and eliminate nesting in or near these groves. Damage assessment will be conducted in these groves in October of 1989.

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Seasonal Variation in Habitat Use by Great-Tailed Grackles in the Lower Rio Grande Valley[1]

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Habitat use by great-tailed grackles was measured by performing weekly censuses of birds in 6 different habitat types: chaparral, citrus groves, feed lots, pastures, residential areas, and agricultural fields. We found that use of chaparral, citrus, and residential sites was low during the winter months, increased sharply with commencement of the nesting season in April, and declined again by October. Use of agricultural fields and pasture was irregular. Feed lot use was low during the summer, but high from October - April with October and March migration peaks. An overall sex ratio of 1.3 females/male was observed with skews from this ratio related to the different life history requirements of the sexes.

INTRODUCTION

The great-tailed grackle (Quiscalus mexicanus) is an abundant permanent resident of the lower Rio Grande Valley of Texas where it is a serious pest on many of the agricultural products of the region. Grackles are not new to the area; they are native, as is testified by accounts from early ornithological investigations in the region (Lawrence 1853:12, Dresser 1865:493). Sennett (1878:28) notes that the species was abundant in towns and in colonies along watercourses. He also mentions that they occurred in chaparral where they showed a marked preference for breeding in stands of ebony (Pithecellobium flexicaule).

The past few decades has seen a marked increase in grackle numbers and a widening of their distribution to the point where they are no longer confined to towns, rivers, and thorn forest. As 98% of the Valley's 1,116 sq km of land surface has been converted to agriculture and residential uses, the grackle has become ubiquitous. The birds are not, however, evenly distributed, and their habitat preferences change through the course of an annual cycle.

Development of a clear understanding of the habitat requirements for grackles is important for the formulation of control strategies. We began investigation of the bird in January 1987, as part of a project designed to provide methods for reducing grackle damage to citrus fruit. Grackles occur in all of the 6 major habitat types in the Valley. In this paper we report on how preferences for these habitats change during the year. We also examine sex ratios by season and habitat type.

METHODS

Habitat use surveys were conducted once/week from the first week of April, 1987 to the last week of April, 1988 for selected sites in Hidalgo and Cameron counties. Twelve census sites were chosen in each county, 2 for each of the 6 major habitat types. The habitat types are: 1) Chaparral, 2) Citrus Groves, 3) Residential Areas, 4) Agricultural Fields, 5) Pastures, 6) Feed Lots. The total number of males and females within a 200-m radius of the census point was recorded using 10x40 binoculars. Information on the movements and behavior of the birds was noted. Censuses were conducted between 0800-1000h and 1400-1600h. The time at which each point was visited was changed weekly.

RESULTS AND DISCUSSION

Chaparral

Only 4,700-ha of chaparral remain in the lower Rio Grande Valley. Dominant tree species in this habitat include: mesquite

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(Prosopis glandulosa), ebony, brazil (Condalia obovata), and spiny hackberry (Celtis pallida). Canopy height is 3 to 4-m away from the river, up to 8 or 9-m along the flood plain. Undergrowth is tangled with extremely dense growths of forestiera (Forestiera spp.), snake eyes (Phaulothamnus spinescens), lime pricklyash (Zanthoxylum fagare), and other shrub species. Canopy cover is 95-100% in ungrazed chaparral, so there is little in the way of ground cover except at openings.

Grackles prefer chaparral as a breeding area above all other habitat types. Adult males begin moving to chaparral and establishing display territories in March (fig. 1). They are joined by adult females in April and nesting is well underway by May. Young are produced in June. Depending on the availability of water, birds may continue to use chaparral into August and September. The habitat is also used for roosting during the post-breeding period into October. However, by the end of October, there is very little grackle activity in chaparral, and numbers remain low until March (fig. 1).

Citrus Groves

There are approximately 11,760-ha of citrus in the Valley (Waggerman 1988), down from nearly 30,000-ha prior to the December freeze of 1983. Citrus includes a number of different fruit varieties for both grapefruit and oranges. The trees are spaced 2 to 3-m apart in rows that are 4 to 5-m apart. Mature trees are 4 to 5-m tall, forming an almost continuous canopy down a given row. Most groves are located near a water source, usually an irrigation ditch, and are irrigated as needed throughout the year. The cycle of citrus production begins with flowering in March. The tiny fruits set in April and reach full development by October. Most of the fruit is harvested in November, but some varieties, e.g. Valencia oranges, are harvested in January or February.

Grackles use the groves primarily as breeding colony habitat, as a substitute for chaparral. The dense crowns of mature citrus and the usual proximity of water to the nest sites in citrus groves serve as the main apparent attractants. The pattern of grove use by grackles is very similar to that seen in chaparral (fig. 2). The birds begin moving into groves in March and remain through the summer breeding and post-breeding periods until October when grove use drops sharply. Grackle use of groves after this time is spotty. Some groves, particularly those with late-maturing fruit, continue to be visited by large numbers of grackles through the winter period. For instance, a small (2-ha) grove on Trenton Road was visited daily in February, 1987 by a flock of over 200 grackles, mostly males. The birds were feeding on mature Valencia orange fruit. When the remaining fruit was finally harvested, the birds no longer visited the grove.

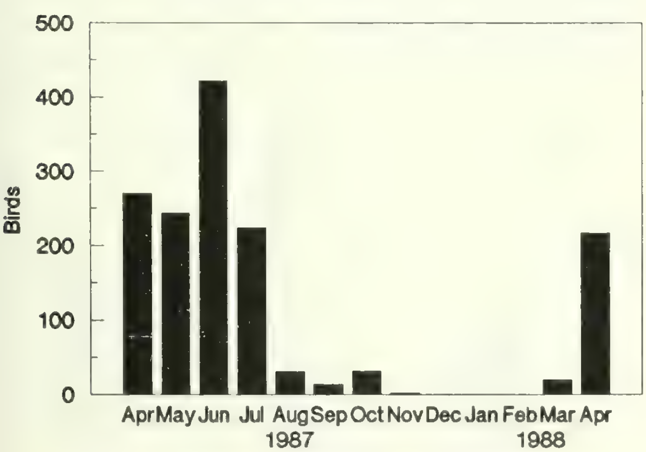

Figure 1.--Grackle use of chaparral.

Residential

The "Residential" category includes a variety of habitat types: lawns, gardens, bird feeders, dumps, and groves of hackberry (Celtis laevigata), palm (Washingtonia spp.), and many other native and exotic species. As a result, use patterns depend on the types of microhabitats chosen to sample. Our 4 sites were mainly park-like with grassy lawns and scattered trees. Therefore, the use pattern is similar to that of citrus and chaparral since the trees were used as breeding colony sites (fig. 3).

Pasture

We use the term "pasture" to refer to areas of actively grazed short grass that are kept clear of shrubs. In the Rio Grand Valley, most such sites are "improved" pasture, i.e. they are cultivated and planted with an exotic grass, e.g. coastal bermuda (Cynodon dactylon). Pasture is used by grackles exclusively as a foraging area for arthropods, and as figure 4 shows, it is used throughout the year with peaks in October and March. These peaks probably reflect movements of transient and winter resident grackles moving into or through the Valley from the north in fall and from the south in spring.

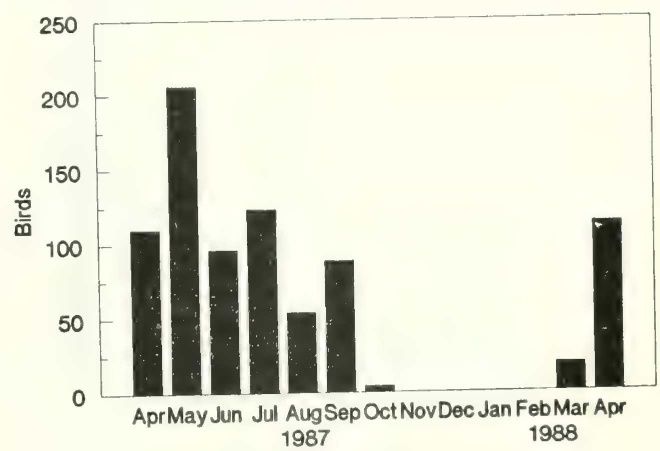

Figure 2.--Grackle use of citrus groves.

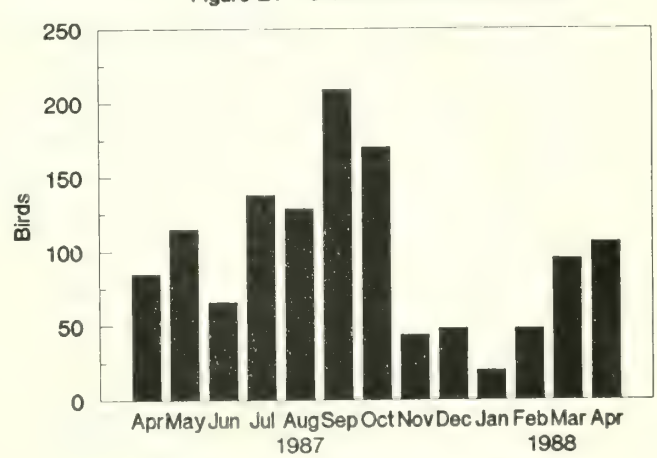

Figure 3.--Grackle use of residential areas.

Agriculture

"Agriculture" includes a wide variety of crops grown in the Valley: sorghum, cotton, sugar cane, melon, tomatoes, beans, aloe, and okra to mention a few. They have in common that they are plowed dirt for a portion of the year, and leafy vegetation the rest of the time. During the periods of plowing and cultivation, grackles are attracted only during and immediately after the cultivation process. Birds flock to machinery working the fields, following behind the vehicles and feeding on the soil organisms exposed. Later, when the crops produce leaves and seeds or fruits, the birds move into the fields to eat either the crop itself (as in the case of young melons) or insects feeding on the crop. They will also eat seeds sown during planting. Peaks in grackle numbers in this habitat reflect responses tuned to the seasonal cropping rhythms of the specific fields included in the sample (fig. 5).

Feed Lots

There are several feed lots, dairies, and graineries in the Valley; places where large amounts of grain are available throughout the year to grackles and other species [primarily pigeons (Columba livia), house sparrows (Passer domesticus), cowbirds (Molothrus spp.), and blackbirds (Aegelius phoeniceus, Euphagus cyanocephalus). The main type of grain available at these sites is sorghum (Sorghum halpense), though corn (Zea mays) silage and other mixed grain feeds are important at feed lots and dairies. These sites are used throughout the year, with

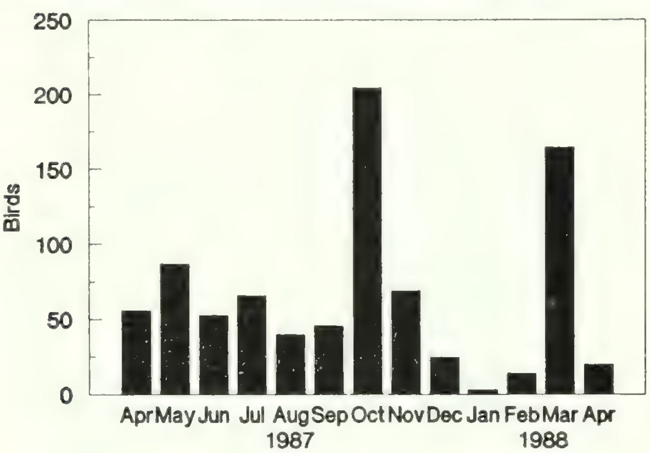

Figure 4.—Grackle use of pasture.

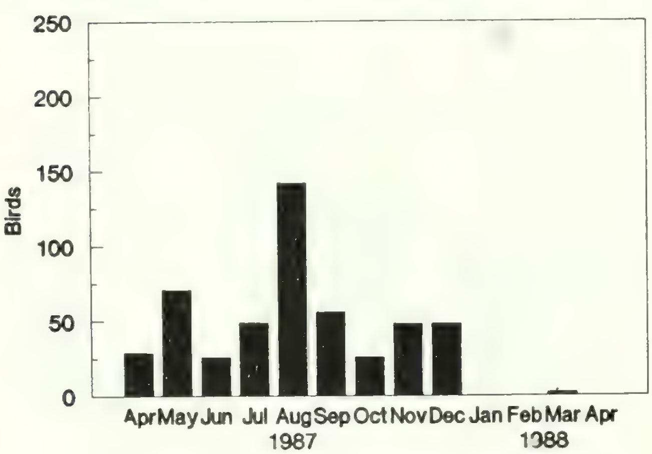

Figure 5.—Grackle use of agricultural fields.

greatest use during the winter months, and lows during the summer when most birds are in chaparral, citrus and riparian breeding colonies (fig. 6). As in the pasture habitats, we see peaks during October and March presumably as a result of the migration of transients through the region.

Sex Ratios

During the entire counting period, we observed a total of 12,797 birds at 1,320 counting sites: 5,562 males and 7,235 females for a ratio of 1.30 females/1 male (table 1). Counts at a point were often heavily skewed in favor of 1 sex or the other. As an example, a flock composed of 28 males and 18 females was observed at 0813-h at Carpenter Dairy on 9 December 1988, while at the same locality at 0826-h on 22 December 1988, there was a flock of 38 females and no males. Single-sex flocks are a fairly common occurrence during the winter months.

Table 1.—Great-tailed grackle ratios of males (M) to females (F) by habitat and season.

	Apr–Jun		Jul–Sep		Oct–Dec		Jan–Mar		Total	
	M	F	M	F	M	F	M	F	M	F
Chaparral	506	431	86	183	30	4	20	0	641	618
Citrus	219	193	123	142	4	0	16	3	362	338
Residential	87	179	168	308	88	174	93	70	436	731
Pasture	86	110	99	53	143	156	78	104	406	423
Agriculture	41	85	112	135	101	21	2	0	256	241
Feed Lots	482	777	301	621	1,132	2,088	1,546	1,398	3,461	4,884

Some of the habitat-related sex ratios have rather obvious explanations. For instance, the preponderance of males in citrus and chaparral from July - December is related to the perch defense behavior exhibited by many adult males during the non-breeding season when these habitats are otherwise relatively deserted by grackles. Males are the first to move into the groves in spring (Mar) to defend their perch sites. Females begin to arrive in April, build their nests, and begin laying and incubating eggs. By June, most females are feeding young while the territorial males continue to defend perch sites attempting to attract females whose earlier nesting attempts may have failed. By July, the groves are occupied mainly by females and young; adult males have

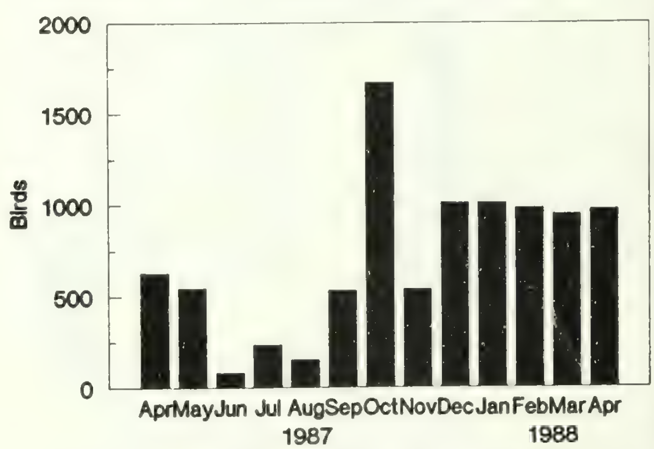

Figure 6.—Grackle use of feed lots.

moved to prime feeding areas, e.g. sorghum fields, pastures, and fallow fields. The higher numbers of females observed in citrus, chaparral, and residential sites from July - September is presumably related to the high movement and activity levels associated with their care of young - at a time when males have begun to desert breeding colonies. However, explanations for sharp sex ratio skews in certain habitats and times of the year will require further investigation. As an example, it is not clear why males predominate in agricultural habitats from October - December.

CONCLUSIONS

Analysis of great-tailed grackle use of habitat in the lower Rio Grande Valley of Texas indicates that birds are dispersed throughout a variety of habitats, particularly during the non-breeding season (Aug-Mar). Concentrations do occur at this time in feed lots on the order of several thousand birds, but numbers even at these locations represent a small portion of the half a million birds estimated to inhabit the Valley. Use of citrus groves during this portion of the annual cycle is irregular and unpredictable with flocks of 200-300 birds occasionally entering groves and damaging mature fruits. However, it is clear that citrus is not a preferred habitat in winter. Grackles concentrate in chaparral, citrus, and residential areas from April - July forming colony sites where trees provide suitable nest placement locations. They often remain in the groves, causing considerable damage, during the immediate post-breeding period (Aug-Sep) if a secure supply of water is available.

Changes in sex ratios during different seasons reflect the different life history requirements of the 2 sexes. Most of the damage to citrus occurs during the late summer months (Aug-Sep), and is done primarily by the females and young that remain in and around the groves attracted to the permanent water supplies in the form of irrigation ditches that are usually available in the vicinity.

ACKNOWLEDGEMENTS

This research was funded through multi-year cooperative agreements with USDA-APHIS and Animal Damage Control. Don Hawthorne, ADC Supervisor for Texas and Martin Mendoza, ADC South Texas Regional Supervisor, were particularly helpful with the project. Animal Damage Technicians John Hobbs, Joe Palacios, Fred Leon, and Judson Dosher assisted with the collection of field data as did Alan Storey, Paul Schulz, John Rappole, Jr., John Norwine, Jody Palacios, David Peterson, David Johnson, and Ralph Bingham of Caesar Kleberg Wildlife Research Institute (CKWRI). Sam Beasom, Director of CKWRI served as overall project leader. Fred Guthery, Research Scientist for CKWRI, assisted with the project and the first year data collection and analysis. Nancy Koerth performed statistical analysis. Yolanda de los Santos and Annette Heffelfinger helped with manuscript preparation. David Bergman generated the graphs and tables. And special thanks to Becky Ware Davis, Operations and Public Relations Officer for CKWRI, who kept track of all of us.

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Fall Food Habits of Double-Crested Cormorants in Arkansas[1]

Albert E. Bivings, Michael D. Hoy, and Jeffery W. Jones[2]

Abstract.--One hundred forty-eight double-crested cormorants (Phalacrocorax auritus) were collected in October-December 1988. Some were collected while actively feeding, but most were collected at loafing or roosting areas. Of the 135 with fish in them, 79% contained gizzard shad (Dorosoma cepedianum) and 16% contained centrarchids (mostly Lepomus sp.). The rest contained a variety of aquaculture (commercially raised) fish. Fish prey weights were estimated from total length of prey items and use of published length-weight tables. Total weights of prey ranged from 39 to 455g with a mean of 185g. This was felt to be a conservative estimate of 1/2 daily consumption. Thus, these birds appear to be eating approximately 370g (0.81 lbs.) of fish per day. Potential impact at aquaculture facilities will depend on the value of the crop.

INTRODUCTION

Double-crested cormorants, formerly year-round residents in Arkansas, are a common migrant throughout the state. The last known nest in the state was observed in 1951 at Grassy Lake (Hempstead county). Recently, birds have been seen during the summer on Lake Millwood, but no nests were observed. Band returns indicate the principal sources of Arkansas cormorants are from Saskatchewan, Manitoba, Wisconsin, and North and South Dakota (James & Neal 1986).

Commercial fisheries in the Great Lakes regions suffered increasing depredation problems from cormorants during the period 1920-1945 (Craven and Lev 1985). Some control measures were initiated in the period between 1946-1950. However, problems subsided as cormorant populations declined approximately 80% in the Great Lakes region from 1950-1978 (Postupalsky 1978). Principal reasons listed for this decline were DDT, DDE, DDD, PCB, other contaminants, and persecution by fishermen (Craven and Lev 1985). These trends have been reversed with a subsequent rise in the populations (Vermeer and Rankin 1984).

The apparent increase in the wintering population of cormorants in the South prompted a study of food habits on Texas reservoirs (Campo, et al. 1988) and this study in Arkansas. The purpose of this study was to attempt to identify and quantify prey items of double-crested cormorants in the fall, when population of both cormorants and aquaculture fish are high. The authors would like to thank Messrs. Neal Anderson, I.F. Anderson, Bob Goetz, Mike Freeze, Danny Nixon, Howard Hammans, Charles Summerhill, David Yocum, Jerry Williamson, and the many others who assisted this project. Thanks are also due to T. Booth and R. Owens for their support and editorial assistance.

STUDY AREA AND METHODS

The study was conducted from 18 October through 05 December 1988 in central and southeast Arkansas at various aquaculture facilities.

Prior to collection, each facility was surveyed to determine the number of birds present and their location. Most cormorants were collected with shotguns, although a few were taken with rifles. Birds were taken either at the feeding site or transiting to or from roosting or loafing sites. Collection of downed birds was simplified by use of trained retrieving dogs.

Cormorant esophagus and stomach contents were removed and prey items taxonomically identified. Fish prey consumed were classified to either genus or species. Prey were counted by species and total length of each was measured to the nearest 6 millimeters (1/4 inch). Numbers and length of each prey species for each bird were recorded and tabulated. Mean total length was computed for each prey species consumed. Total weight of prey consumed was estimated when possible for each sample bird based on published length-weight tables (Carlander 1969).

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. (Colorado State University, Fort Collins, April 18-19, 1989).

[2]United States Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Stuttgart, Arkansas.

RESULTS AND DISCUSSION

During this study, 148 cormorants were collected and examined for esophageal/stomach contents. Of the 135 with food items (91%), 106 (71.6%) contained gizzard shad (Table 1). Mean number of shad per bird was 4.87 and mean total length of shad was 149 mm (5.85 in.) (Table 2).

Total biomass consumed was calculated for 112 of the 135 with prey items based on our ability to determine prey live weights from existing tables. Total biomass ranged from 39g to 455g with a mean of 185g per feeding.

The results of this study were similar to those found in Texas (Campo et al. 1988) and Wisconsin (Craven and Lev 1985) in that rough fish were consumed most of the time and the average size prey was about 150 mm (5.9 in.). Our study did show a greater reliance on commercially important species in our small December sample (N=15) where 33% of the cormorants contained channel catfish. This indicates a potential seasonal shift to catfish that has been suggested by catfish producers. Campo, et al. (1988) noticed a similar decline in shad consumption over time indicated. This may be due to changing shad abundance, vulnerability, or to differential thermal response between shad and aquaculture species.

Since cormorants were full of fish throughout the day, biomass estimates are felt to approximate 1/2 daily consumption. Similar thoughts were compiled by Campo et al. (1988) and Bennett (1970). Our daily consumption of 370g (0.81 lb.) is greater than the hypothetical estimates developed by Schramm, et al. (1987) in Florida, and similar to observed data from other studies (Campo et al. 1988, Bennett 1971). The maximum value of 910g (2 lbs.) per day also agrees with Bennett (1971).

While the occurrence of aquaculture fish is low, it is also important to note that several very high value species were identified. The wholesale value of the single grass carp was about $4; while koi are worth $5-10 each. Thus, a small percentage of the population could produce high dollar damage to an individual producer. Also, if there is a shift to commercially important fish later in the winter, mean consumption of 370g (.81 lb.) of fish by the expanding population of wintering cormorants may result in substantial economic impact to southern fish farmers. Furthermore, cormorant predation on spring brood stock could be disastrous. Additional data needs to be collected on spring food habits when cormorant populations are high and shad populations are reduced.

Table 1.--Occurrence of prey species in esophagus/stomach of double-crested cormorants in October - December 1988 in Arkansas.

Prey Species	Number of Birds	Percent of Total
Shad	106	71.6
Channel Catfish	10	6.8
Bluegill	9	6.1
Green Sunfish	9	6.1
Golden Shiner	7	4.7
Crappie	3	2.0
Goldfish	2	1.4
Koi	1	0.7
Unidentified Sunfish	1	0.7
Grass Carp	1	0.7
Unidentified	13	9.0
		109.8

[1]Total exceeds 100% because birds had more than 1 prey species.

Table 2.--Mean total length of prey species found in double-crested cormorants October - December 1988 in Arkansas.

Species	$\bar{x}$TL (mm)
Shad	149
Channel Catfish	227
Golden Shiner	88
Goldfish/Koi	140
Bluegill	195
Green Sunfish	86
Grass Carp	178
Crappie	167

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Evaluation of Predator Guards for Black-Bellied Whistling Duck Nest-Boxes[1]

Raymond L. Urubek[2]

Abstract. I evaluated the effectiveness, suitability, and expense of 2 styles of predator guards for black-bellied whistling duck (Dendrocygna autumnalis) nest-boxes. Guards evaluated were galvanized bottom-attached shrouds and razor-ribbon wire. Both guards were effective against ground dwelling predators. The group not fitted with guards suffered a 55% overall depredation rate.

INTRODUCTION

Large-scale erection of artificial nesting structures for waterfowl has been a management tool for at least 4 decades (McLaughlin and Grice 1952, Belrose 1976). Most of these artificial nest structures were constructed to benefit wood ducks (McLaughlin and Grice 1952, Strange and Cunningham 1971, Bellrose 1976). Predation by ground dwelling species, primarily raccoons (Procyon lotor), and to a lesser extent avian species has often negated the beneficial effects of nest-boxes (Bellrose et al. 1964, Bolen 1967b).

The black-bellied whistling duck is a Neotropical species whose northern breeding distribution extends into southern Texas and regularly occurs as far north as Refugio County (Belrose 1976). Whistling ducks adapt readily to artificial nest structures (McCamant and Bolen 1979). Efforts to provide artificial nest-boxes for whistling ducks began in the early 1960's (Bolen 1967b) and have become more common in recent years (O'Kelley 1987). O'Kelley (1987) found that proper predator deterrents, reduced competition for nest-boxes, and proper density and location of boxes could increase the efficiency of a box-management program. Bolen (1967b) classified nest box failures into 2 groups, abandonment and predation.

My focus in this paper is an investigation of predation. Unlike the wood duck, whose major nest predator is the raccoon, snakes, particularly the Texas rat snake (Elaphe obsoleta) destroy more nests than any other single predator (Bolen 1967a). Although Bolen (1967a) ranked the raccoon second among nest predators, he felt that they were the most important predator because of the cunning and methodical manner in which they destroyed bird nests.

Information presented here was collected during the Welder Wildlife Foundation's yearly nest box maintenance and refurbishment program. I stress that this information should be approached from a demonstration viewpoint rather than that of a scientific study. There were unequal sample sizes, and many interconnected variables that make statistical analysis of the results questionable.

DEMONSTRATION AREAS

Two oxbow lakes and 5 stock ponds were used in this demonstration. All sites were located within the boundaries of the Welder Wildlife Refuge. The 3,158 ha refuge is located 40 km north of Corpus Christi in San Patricio County, Texas. The Aransas River, a permanent waterway, forms the north and east boundaries. The refuge lies in a transition zone between Gulf Prairies and Marshes and South Texas Plains (Gould 1975). Over 1400 species of flowering plants and ferns occur in this area, mostly of tropical and subtropical origin. Drawe et al. (1978) and Drawe (1988) further describe the soils and vegetation found on the refuge. The 30 year average annual rainfall is 91 cm.

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[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Marriott Hotel, Fort Collins, CO, April 17-20, 1989]. Contribution 337, Rob and Bessie Welder Wildlife Foundation.

[2]Raymond L. Urubek is a Research Biologist, Rob and Bessie Welder Wildlife Foundation, Sinton, TX.

Monthly rainfall means indicate a bi-modal pattern with peaks in spring and early fall (Low 1970, Kie 1985).

METHODS

Data presented here were collected from nest boxes erected before 1982, in 1982, in 1987, and in 1988. Table 1 presents the number and type of boxes available during the 1987 and 1988 breeding seasons.

Table 1.--Nest-boxes and predator guards available during the 1987 and 1988 nesting seasons.

Box and Guard Type	1987	1988
Wooden-Single Box Metal Shroud	11	11
Wooden-Double Box Metal Shroud	26	26
Wooden-Single Box No Guard	16	16
Plastic Box No Guard	16	16
Parks & Wildlife Razor-Ribbon Wire	0	24
TOTAL	69	93

Boxes erected prior to and including 1982 were of the type described by Bolen (1967a) and included single box units and units that employed 2 nest boxes per pole (fig. 1). Nest structures erected in 1987 included a modified version of Bolen's nest box (1967a, fig. 2) and a modified plastic bucket (Griffith and Fendley 1981) (fig. 3). Boxes obtained from the Texas Parks and Wildlife Department's Wood and Tree Duck Production Project (fig. 4) were erected in April 1988.

Predator guards were of two types; galvanized metal shroud (Bolen 1967b, fig. 1), and razor ribbon wire (fig. 5). Plastic 5-gallon buckets and modified Bolen boxes were not fitted with guards.

Each box was checked in early spring. Old nesting material was removed and a fresh bed of pine bark mulch was installed. Boxes were subsequently examined for usage at 2-3 month intervals through the nesting season. Each box was checked an average of 3 times per year. Nest predators were identified following the criteria of Reardon (1951).

RESULTS AND DISCUSSION

Overall nest box use by black-bellied whistling ducks was 85% and 45% for the years 1987 and 1988, respectively.

Figure 1.--Wooden-double box unit adapted from Bolen (1967a), with metal shroud.

Figure 2.--Wooden-single box modified from Bolen (1967a), shown without predator guard.

Figure 3.--Modified Griffith and Fendley (1981) plastic 5-gallon bucket nest-box.

McCamant and Bolen (1979) reported an 81% overall whistling duck nest-box use during the 12-year period 1964-75. The low use of boxes in 1988 was caused by drought conditions that left the oxbow lakes dry and water levels of the smaller ponds very low.

Predation was limited to unprotected wooden boxes (55%). Bolen (1967a) found predation rates in unprotected boxes and natural cavities of 23% and 41%, respectively. I suggest that the predation rate observed is higher because of an abnormally large raccoon population and because boxes were placed immediately adjacent to the ponds. McLaughlin and Grice (1952) reported an overall raccoon predation rate of 41% on wood duck nest boxes; however, considering only boxes placed in swamp areas the predation rate rose to 78%. Rat snakes were found in 1 unprotected box and on the ground at the base of a box fitted with a metal shroud. A western cottonmouth (Agkistrodon piscivorus) was found on the ground at the base of a box protected by razor-ribbon wire. There was no evidence of raccoon or snake predation on nests in plastic boxes where the distance from mounting pole to entrance hole was greater than 330 mm.

Galvanized metal shrouds are expensive ($28); however, they are the most durable and can be manufactured to fit the mounting structure. Razor ribbon wire is an inexpensive ($4) alternative if the mounting structure will accept it. Although no accidents have been reported from the use of razor ribbon wire, I suggest its use be restricted to remote areas. If a predation problem arises while using plastic buckets, an inverted 5-gallon bucket (fig. 6) is an inexpensive ($1/unit) solution and can be modified to fit many existing mounting structures. In the south Texas climate I expect the longevity of plastic buckets, razor ribbon wire, and galvanized metal shrouds to be 3, 5, and 8 years, respectively.

Figure 4.--Nest-box provided by the Texas Parks and Wildlife Dept., shown with razor-ribbon wire guard.

Figure 5.--Razor-ribbon wire guard, shown as mounted on Texas Parks & Wildlife box.

Figure 6.--Modified plastic 5-gallon nest-bucket (Griffith and Fendley 1981), showing additional bucket mounted at base of nest-bucket.

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Field Trials of Alpha-Chloralose and DRC-1339 for Reducing Numbers of Herring Gulls[1]

Paul P. Woronecki, Richard A. Dolbeer, and Thomas W. Seamans[2]

Abstract.--We compared the potential of Alpha-chloralose (A-C) and DRC-1339 to reduce a nesting population of herring gulls at an industrial site in Ohio in 1988. Almost all treated baits were consumed by gulls but only about one affected gull was noted for every 10 baits consumed of either chemical. A test indicated our DRC-1339 baits, containing 3.7 - 7.4 times the published LD_{50} value, were not lethal to most captive herring gulls living in fresh water. LD_{50} values of A-C and DRC-1339 need to be more precisely estimated for gull species in fresh and salt water environments.

INTRODUCTION

Gull populations have increased in recent years in North America resulting in urban nuisance problems, agricultural crop damage and reductions in populations of other bird species that compete for nest sites (Ludwig 1966, Drury 1973, Conover 1983, Blokpoel and Tessier 1986). In the western Lake Erie region, ring-billed (*Larus delawarensis*) and herring (*Larus argentatus*) gull populations during autumn migration have increased 20- and 6-fold, respectively, in the past 30 years (Dolbeer and Bernhardt 1986).

There are 95 chemical products currently registered by the U.S. Environmental Protection Agency (EPA) to control bird damage and nuisance problems in the United States (Eschen and Schafer 1986). Only four include gulls as target species: Polybutene and Polyisobutylene - both nontoxic tactile repellents; 4-Aminopyridine (Avitrol) - a lethal frightening agent; and 3-chloro-4-methyl-benzenamine HCL (DRC-1339), a toxicant. Currently, DRC-1339 can only be used by U.S. government personnel to control herring, and great black-backed gulls (*Larus marinus*) in the coastal nesting areas of Delaware, New York, New Jersey, Connecticut, Rhode Island, Massachusetts, New Hampshire and Maine. There are no gull toxicants registered for field use outside the coastal nesting areas of the Northeastern U.S. EPA is currently considering the expansion of the present registration to include ring-billed gulls and other geographical locations.

USDA/APHIS/ADC operational personnel have indicated a need for expansion of present registrations or development of new chemical registrations for gull control (Fagerstone and Schafer 1988). The objective of this pilot field study was to compare the potential of a presently unregistered chemical, alpha-chloralose ($C_8H_{11}Cl_3O_6$) and the registered gull toxicant DRC-1339, to reduce a nesting population of herring gulls in Ohio.

DESCRIPTION OF CHEMICALS

Alpha-chloralose (A-C) is a narcotic which depresses the cortical centers of the brain but has no effect on the medulla (Borg 1955, Crider and McDaniel 1967). A-C has proven to be relatively safe in capturing birds for research (Murton et al. 1963, 1968, Crider and McDaniel 1966, 1967, 1969, Williams 1966, Williams et al. 1966, Crider 1967; Martin 1967, Crider et al. 1968, Austin et al. 1972, Cline and Greenwood 1972, Williams and Phillips 1972, 1973, Pomeroy and Woodford 1976, Holbrook and Vaughn 1985).

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Fort Collins, April 18-19, 1989]

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A-C has also been used to reduce populations of several species of birds (without endangering nontarget species) that either were a nuisance, potential hazard to aircraft or harmful to agriculture (Anon. 1960, 1962, Thearle 1960, 1969a, 1969b, Ridpath et al. 1961, Murton 1962, 1963, Murton et al. 1965, Caithness 1968, Thearle et al. 1971, Cyr 1977, Feare et al. 1981, Dolbeer 1987). Several bird and mammal species have had a LD_{50} and a ED_{50} [sometimes referred to as Temporary Immobilization dose (TI_{50}) not to be confused with the therapeutic index (TI)] established[3].

The ED_{50} of A-C for wild birds ranges from 5.6 - 85 mg/kg and the LD_{50} from 32 - 400 mg/kg with a safety factor from 3.2 - 23. The LD_{50} range for rats, cats and dogs is 200-600 mg/kg (Goldenberg 1893, Giban 1950 and 1951, Borg 1955, Ridpath et al. 1961, Schafer and Cunningham 1972, Pesticides Board 1977, Cunningham et al. 1987).

A-C has been registered as an avian control agent in Great Britain, France, New Zealand and Australia. However, limited attention has been given to the use of A-C as an agent for the capture or poisoning of gulls. Borg (1955) had a kill rate of 93% for herring gulls in Sweden with an A-C bait concentration of 100 mg in 80 g fish (0.125% A-C by weight). Caithness (1968) killed at least 85% of a breeding colony of 2,500 southern black-backed gulls (Larus dominicanus) in New Zealand with 5-g bread baits each containing 200 mg of A-C (3.77% A-C by weight). Control activities on lesser black-backed gulls (Larus fuscus) and herring gulls have been conducted at their breeding sites during egg incubation in Great Britain. A-C treated bread squares placed in nests were eaten by the adults (Mitchell 1976). However, neither the ED_{50} nor LD_{50} for A-C have been established for any gull species.

Physical, chemical and toxicological properties of DRC-1339 have been summarized by DeCino et al. (1966) and Schafer (1979). DRC-1339 is a slow-acting toxicant that impairs the circulatory system, causing uremic poisoning and congestion of major organs. Death can occur up to four days after ingestion. DRC-1339 is registered in the U.S. to reduce populations of several species of birds that are a nuisance or harmful to agriculture (Eschen and Schafer 1986) and since 1969 it has been used to reduce gull populations in Maine and Massachusetts (Gramlich 1969, Ladd 1970, Snow and Gramlich 1971[4], and Drennan et al. 1986, 1987). The only LD_{50} information presently available for gulls was obtained by Wetherbee (1968) for herring gulls on the east coast and estimated to be 2.9 mg/kg (Schafer 1979). However, the actual weights of the gulls tested were not considered when dosing or determining the LD_{50}.

STUDY AREA AND METHODS

The study was conducted in 1988 at the Lower Lake Dock Company (LLDC), a 30-ha nesting and loafing site for herring gulls in Sandusky, Ohio adjacent to Sandusky Bay of Lake Erie (fig. 1). Gulls have created various problems at the LLDC, a coal shipping facility, primarily by causing power outages at the transformer station and disrupting workers through aggressive defense of nests and young. The LLDC is 0.4 km west of Turning Point Island, a 2.0-ha man-made island with two adjacent 4 x 450-m breakwalls, that has supported a nesting colony of herring gulls since at least 1977 (Scharf 1978, Dolbeer et al. 1988).

Prebait was made by spreading 12 g of soft margarine on a slice of soft white bread and covering with another slice. The sandwich was then pressed firmly with a flat board and sliced into 18 pieces. Each piece weighed about 3.3 g. Prebaiting was conducted on 12 and 13 April by spreading about 1,000 baits on the ground each day at various sites at the LLDC.

Baiting with A-C was conducted between 0800 and 1000 on 14, 15, 18, 20 and 22 April (table 1). A-C was mixed with the margarine to a level of 4, 8 or 16% by weight, resulting in bread baits containing 26, 53, or 106 mg of A-C. Baits were placed in nests or spread out in lines at 2- to 3-m intervals where concentrations of gulls were located. Bait sites were observed to determine the time of initial bait consumption and initial reaction and immobilization.

DRC-1339 (obtained from Denver Wildlife Research Center) was mixed with margarine to a level of 1.6 or 3.2% by weight. This resulted in each bread bait containing 10.8 or 21.6 mg of DRC-1339, 3.7 to 7.4 times the LD_{50} value of 2.9 mg/kg reported for herring gulls (Schafer 1979). (Note: herring gulls in our study averaged about 1 kg in weight - see table 3). Baiting was conducted on 27 April, 3 May and 13 May in the same manner as with A-C.

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[3] LD_{50} is the median lethal dose that produces death and the ED_{50} is the median effective dose that produces a defined effect (e.g., capture) in half of the population to which the drug is administered and the safety factor (Therapeutic Index) is the ratio of LD_{50} to the ED_{50} ($TI=LD_{50}/ED_{50}$).

[4] Snow, W. O., and F. J. Gramlich. 1971. Gull control, Matinicus Rock and Green Island (Petit Manan), Maine. U.S. Fish Wildl. Serv., Region 5, Memorandum. 3 pp.

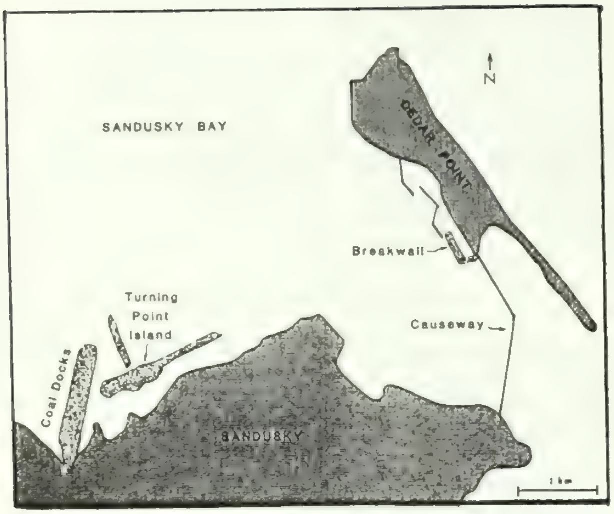

Figure 1.--Map of Sandusky Bay at Sandusky, Ohio showing location of coal docks, Turning Point Island and breakwalls where herring gulls nested, 1988.

A rough estimate of the gull population at the LLDC was made at the time of each baiting by visually scanning the area with binoculars from several observation points. All baits not consumed within two hrs of placement were retrieved. After A-C baitings, the coal docks and surrounding loafing areas up to 2 km away were searched for dead or affected gulls during a 3-4 hr period. After DRC-1339 baiting, similar searches usually were made 24 hrs later and then at 1-2 day intervals for 4 days. Dead birds were retrieved and buried; incapacitated gulls were placed in a 2.5 x 2.5 x 2.0-m holding cage with food (fish offal) and water until they either recovered or died. The Ohio Division of Wildlife and the Sandusky Health Department were notified of our study and requested to report to us any dead or affected gulls brought to their attention.

On 9 May, 12 herring gulls that had been captured at LLDC with A-C baits during the April baitings were each force-fed a DRC-1339 treated bread bait and placed in a 2.5 x 2.5 x 2.0-m holding cage with food and water. Three groups of 4 gulls each received baits with 10.8, 21.6 or 43.2 mg of DRC-1339. Gulls were observed at 24-hr intervals for 4 days.

RESULTS

A-C Baitings.--A total of 1,597 A-C baits were placed at the LLDC during the four baitings of which 1,308 were consumed primarily by gulls and a few starlings (*Sturnus vulgaris*) (table 1). Immobilization occurred as quickly as nine minutes after bait was consumed although most gulls did not show affects for 15 to 20 minutes. Of the 99 affected gulls retrieved, 34 survived. An additional 37 affected gulls were noted floating in the bay, but we were unable to retrieve them because of rough water. Thus, we recorded a total of 136 affected gulls or about 1 gull for every 10 baits consumed. About 1,000 gulls were at the LLDC during these baitings and the subsequent DRC-1339 baitings.

Gulls reacted to affected gulls in various ways. Often gulls would fly, spiraling high above the LLDC. On occasion, a gull would use its bill to tug at an affected mate. Most affected birds were retrieved within 1 km of the LLDC, many becoming incapacitated while in the water of the bay. Two immobilized gulls were found 6 to 7 km from the LLDC by individuals who brought them to us via Ohio Division of Wildlife personnel. Bait shyness from one day to the next did not appear to be a problem. However, on a given day, once gulls started reacting, feeding ceased although gulls did not abandon the LLDC.

DRC-1339 Baitings.--Of 1,570 baits placed out during three baitings, 100% were eaten, almost all by gulls but also by a few starlings (table 1). Initial deaths occurred within 24 hrs but most occurred 48 to 72 hrs after consumption (table 2). A total of 145 birds were retrieved or about one gull for every 11 baits consumed. Bait shyness was not a problem.

Almost all recoveries were within 1 km of the LLDC. Twelve decomposed gulls found dead in a field 4 km southwest of LLDC on 12 May were probably DRC-1339 poisoned gulls but they may have been A-C poisoned birds.

DRC-1339 Bioassay.--Although the lowest dose we evaluated (10.8 mg DRC-1339) was about 3.7 times the published LD_{50} value for herring gulls (Schafer 1979), three of the four gulls survived. One out of 4 gulls dosed at 21.6 and 43.2 mg DRC-1339 survived (table 3).

DISCUSSION

Bait acceptance with both chemicals was excellent, with over 2,800 baits being consumed by gulls. Curiously, however, only about one dead or affected gull was found for every 10 baits consumed of either chemical, and the population of about 1,000 gulls at the LLDC showed little or no decline during the study.

For A-C, ED_{50} and LD_{50} values have not been determined for gull species, but data for other avian species suggest that the doses we provided per bait (26 to 106 mg) should have been sufficient to immobilize a gull consuming a single bait. We know that multiple baits commonly were consumed by individual gulls, especially during the initial two baitings with A-C when we did not spread out the bait as widely as in later baitings. This may explain some of the discrepancy between baits consumed

Table 1.--Alpha-chloralose (A-C) and DRC-1339 baiting of herring gulls at Lower Lake Dock Co., Sandusky, Ohio, 1988.

Date	Chemical	Mg of chemical per bait[1]	No. of baits put out	No. of baits eaten	Time from 1st feeding to first immobilized gull	No. of affected gulls retrieved	Min. no. of affected gulls not retrieved	Min. total affected gulls	No. of retrieved gulls surviving	Min. no. of affected gulls/ bait consumed	Estimated no. of gulls at LLDC	Nontargets retrieved
14 Apr	A-C	26	288	288	15 min	18	4	22	6	1:13	1,200	
15 Apr	A-C	53	372	284	14 min	13	9	22	5	1:13	1,200	1 starling
18 Apr	A-C	53	246	221	16 min	16	0	16	7	1:14	1,000	
20 Apr	A-C	106	270	103	9 min	6	0	6	1	1:27	1,000	1 starling
22 Apr	A-C	53	421	412	17 min	46	24	70	15	1:6	1,000	
Total for A-C			1,597	1,308		99	37	136	34	1:10		
27 Apr	1339	10.8	358	358	24 hr	35	0	35	0	1:10	900	1 starling
3 May	1339	10.8	600	600	24 hr	38	0	38	0	1:16	1,100	
13 May	1339	21.6	612	612	24 hr	72	3	75	0	1:8	1,000	
Total	1339		1,570	1.570		145	3	148	0	1:11		
Total for 1339 and A-C			3.167	2,878		244	40	284[a]	34	1:10		

[1]Bait was made by spreading a mixture of 12 g of A-C or DRC-1339 and soft margarine on a slice of white bread and covering with another slice. The sandwich was then pressed firmly with a flat board and sliced into 18 pieces. Each piece weighed about 3.3 g and contained 10.8 to 106 mg of A-C or DRC-1339, depending on the level of A-C or DRC-1339 in the margarine (1.6 to 16%).

[a]In addition, 6 dead or affected gulls were reported in Sandusky by the Health Department, 6 were picked up around Sandusky Bay within 2 km of coal docks and 12 were located in field 4 km from coal docks. We were unable to determine if these were A-C or DRC-1339 poisoned gulls.

and gulls affected. However, we suspect that some unknown but substantial number of gulls dispersed from the LLDC before becoming immobilized and were never located.

For DRC-1339, the doses provided per bait were 3.7 to 7.4 times the published LD_{50} value for herring gulls and each gull consuming a bait should have died. However, the bioassay we conducted with 12 gulls indicated that either the chemical used was not pure or the herring gulls on Lake Erie have higher LD_{50} values for DRC-1339 than those published. Drennan et al. (1987) noted similar concerns about reduced toxicity of DRC-1339 in a program in Maine for controlling nesting populations of herring gulls and great black-backed gulls.

The fact that the population of gulls at the LLDC did not show a noticeable decline, even considering that substantially more gulls may have died than we recovered, can be explained by the large population of gulls in adjacent areas (fig. 1) such as Turning Point Island (Dolbeer et al. 1988). Gulls at the LLDC probably represented less than 10% of the gulls within a 4 km^2 area and dead gulls could have quickly been replaced. Our findings suggest that problems caused by gulls at the LLDC, such as power outages, can best be solved by erecting wire grid exclusion devices (Blokpoel and Tessier 1984). Poisoning programs at LLDC to reduce populations of gulls will provide only temporary relief at best as long as the gull populations are thriving in adjacent areas.

Although we do not recommend poisoning programs as a means of solving gull problems at LLDC, we recommend further testing of both A-C and DRC-1339 on gulls to develop these toxicants for other situations. Each chemical has unique attributes that would make it preferable in particular situations. A-C is fast acting and, depending on dosage, gulls can either be killed or captured alive. Although bait shyness occurs once gulls start reacting to A-C (usually about 15 min after initial bait consumption), this shyness does not seem to carry over to subsequent days. DRC-1339 is slow acting and thus bait placement and feeding by gulls can occur over an extended period on a given day without bait shyness developing.

For A-C, ED_{50} and LD_{50} values need to be more precisely estimated for gull species. For future DRC-1339 work, chemical assays should be conducted to ensure chemical purity. Also LD_{50} estimates for gulls from the Great Lakes and other regions are needed. DRC-1339 primarily affects the renal system; therefore, there may be a difference in the toxicity of this chemical for gulls living in fresh and salt water environments.

Table 2.--Number of dead herring gulls recovered 1, 2 and 3 or more days after baiting with DRC-1339, Lower Lake Dock Co., Sandusky, Ohio, 1988.

Date of baiting	Mg of DRC-1339/ bait	Number of gulls recovered at 24 hrs	48 hrs	>72 hrs
27 April	10.8	2	18	15
3 May	10.8	3	19	16
13 May	21.6	--[1]	--[1]	72

[1]Searches were not made.

Table 3.--Mortality of captive herring gulls force-fed bread baits with 1 of 3 levels of DRC-1339 on 9 May 1988, Sandusky, Ohio.

Dose (mg of DRC-1339) per bait	No. of gulls	Weight(g) x	SD	Number gulls alive aft[er] 24 hr	48 hr	>72 h[r]
10.8	4	1,053	83	4	3	3
21.6	4	990	179	4	1	1
43.2	4	940	58	3	1	1[1]
Totals	12	994	90	11	5	5

[1]Gull walked with difficulty but flew when released.

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Survey of Animal Damage and Feeding Selectivity of Rabbits in Eastern South Dakota Shelterbelts[1]

Thomas G. Barnes, Emmett J. Keyser, III, and Raymond L. Linder[2]

Abstract.--Animal damage to young shelterbelt trees was measured during 1980-82. Rabbits damaged coniferous trees less than deciduous trees or shrubs. Branch clipping by rabbits was the most common form of damage which varied according to species, experiment, and locality. Rabbits did not feed selectivily with regard to 1, 2, or 3 year old saplings.

INTRODUCTION

Establishment of shelterbelts is expensive and therefore requires careful planning to optimize management objectives. Tree species used will determine a shelterbelt's effectiveness in reducing soil erosion, increasing moisture conservation, enhancing crop protection, reducing farmstead energy costs, and wildlife utilization. Shelterbelts are important habitats for wildlife including ring-necked pheasant (Phasianus colchicus) (Warner and David 1982), white-tailed deer (Odocoileus virginianus) (Popowski 1976), cottontail rabbits (Swihart and Yahner 1984), passerine birds (Martin 1980, Cassel and Wiehe 1980, Yahner 1982b, 1983b), raptors (Norelius 1984), and small mammals (Barnes and Linder 1982, Yahner 1982a, 1983a). Most wildlife exhibit positive values; however, rabbits, deer, and small mammals can have a negative value by injuring and damaging young shrubs and trees (Baer 1980).

Winter browsing by wildlife is often ignored in planning shelterbelts, even though wildlife species may cause damage to some tree species such as crab apple (table 1) (Baer 1980, Swihart and Yahner 1983). Knowledge of feeding selectivity and the extent of animal damage facilitates tree selection by potentially identifying woody species prone to animal damage.

Table 1. Scientific name of plants mentioned in text and tables.

Crab apple	*Malus spp.*
Green ash	*Fraxinus pennsylvanicus*
Hackberry	*Celtis occidentalis*
Common lilac	*Syringa vulgaris*
Tatarian honeysuckle	*Lonicera tatarica*
Blue spruce	*Picea pungens*
Eastern red cedar	*Juniperus virginianus*
Rocky mountain juniper	*Juniperus scopulorum*
Elms	*Ulmus spp.*
Siberian elm	*Ulmus pumila*
American elm	*Ulmus americana*
Dogwood	*Cornus stolonifera*
Ponderosa pine	*Pinus ponderosa*
Red pine	*Pinus resinosa*
Loblolly pine	*Pinus taeda*
Northern white cedar	*Thuja occidentalis*
Snowberry	*Symphoricarpos vaccinoides*
Barberry	*Berberis spp.*
Service berry	*Amelanchier alnifolia*
Willow	*Salix spp.*
White willow	*Salix alba*
Cottonwood	*Populus deltoides*
Robusta poplar	*Populus angulata x P. nigra*
Northwest poplar	*Populus deltoides x P. balsamifera*
Amur maple	*Acer ginnala*
Caragana	*Caragana arborescens*

Quantified data are lacking on animal damage and feeding selectivity of rabbits in shelterbelts on the Great Plains. Previous research focused on (1) local areas where rabbit damage to young trees was extensive (Baer 1980), (2) the establishment and reforestation of conifers (Littlefield et al. 1946, Cayford and Haig 1961, Sartz 1970, Black et al. 1979, Evans et al. 1981), or (3) arboretums or other specialized situations (McCabe 1945, Geis 1954, Swihart and Yahner 1983). We investigated 4 experiments designed to determine the (1) feeding selectivity of cottontails and jackrabbits and their subsequent damage to various tree species and (2) overwinter survival of trees in eastern South Dakota shelterbelts.

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METHODS

Experiments were conducted from 1980 to 1982 to assess animal damage occurring in eastern South Dakota (Brookings County) shelterbelts. A survey of 19 one-year old shelterbelt plantings during fall, winter and spring 1980-81 provided initial data upon which the remaining studies were based. Three experiments were conducted during the winter and spring of 1981-82 to determine effects of sapling age on rabbit damage, amount of damage occurring in 5 to 10 year old shelterbelts, and feeding selectivity of rabbits for 4 baits.

Experiment One

Nineteen shelterbelts, each containing at least 3 rows of trees, planted in the spring 1980 in Brookings County (Barnes 1982) were randomly selected and examined in the fall and following spring for animal damage. Tree species composition was recorded from Soil Conservation Service (SCS) records. Each tree in 4 randomly selected 15.25 m x shelterbelt-width quadrats was examined per shelterbelt.

Individual trees were examined visually. Animal damage was classified and recorded according to animal species causing damage, area of tree injured, and severity of damage (Lawrence et al. 1961). Species causing injury were recorded as rabbit, rodent, deer or domestic livestock. Area of tree injured was recorded as crown, stem, or branch. Severity of damage was recorded as slight, moderate, or lethal, and later grouped as lethal or sublethal. Heterogeneity chi square was used to detect differences ($P \leq 0.05$) in feeding selectivity among tree species.

Experiment Two

A second study was designed to examine differences in feeding selectivity by rabbits due to sapling age of the most common shelterbelt woody species and to determine the efficacy of fencing to control rabbit damage. Twenty shelterbelts were randomly selected from SCS records for study. Shelterbelts contained the following woody species: green ash, hackberry, common lilac, tatarian honeysuckle, blue spruce, and eastern redcedar.

Thirty randomly selected plot pairs (1 fenced and 1 unfenced) of 1, 2, and 3 year-old individuals of each woody species (540 pairs total) were examined in the spring 1982 for signs of animal damage (Lawrence et al. 1961). Fencing was constructed of 2.54 cm mesh x 1 m tall wire held together by wooden laths with sufficent diameter to enclose the complete tree. Hardware cloth, 0.64 cm mesh x 21 cm height, was attached to the bottom of each fence to exclude mice. Fences were placed around the trees during fall 1981 prior to the first snow.

Orthogonal chi square tests were used to detect differences ($P \leq 0.05$) in the amount and severity of damage among 1,2, and 3 year-old trees; among deciduous trees, shrubs, and coniferous trees; and individual tree species within each group. No comparisons between fenced and unfenced trees was made because none of the fenced trees were damaged.

Experiment Three

Seven 5 to 10 year-old shelterbelts were randomly selected from SCS records to assess the amount of rabbit damage occurring to green ash and tatarian honeysuckle, the two most commonly planted trees. Branches of individual trees of each species were examined for signs of rabbit damage in an unreplicated split plot design. Three randomly selected branches on 12 randomly selected trees of green ash and tatarian honeysuckle were examined in the winter 1982 for signs of rabbit injury. Rabbit damage was recorded for each branch and classified as lethal or nonlethal. A split plot analysis of variance (ANOVA) and least significant differences (LSD) were used to test differences ($P \leq 0.0001$) in rabbit damage between shelterbelts and between green ash and tatarian honeysuckle.

Experiment Four

An alternative to controlling problem animals was evaluated by providing 4 alternative forage sources; dried apples, shelled corn, whole oats, and a commercially pelleted rabbit chow (Purina Mills, St. Louis, Missouri). We randomly selected 6 shelterbelts, 2 to 10 years-old, from SCS records for study during the winter 1982. Shelterbelts were divided into 15.25 m quadrats and each of the 4 diets was placed in 4 randomly selected quadrats per shelterbelt. The experiment was replicated during January, February, and March.

Two hundred sixty seven grams of each diet were placed in a plastic gallon milk carton with 1 side cut open to expose bait. Cartons were placed at ground level for easy access and openings were only large enough to allow cottontail rabbits access. Diets were placed adjacent to one another and each diet was randomly assigned a space in each of the 4 quadrats per shelterbelt. Forages were offered during the day and collected the following morning. Orts were returned to the laboratory and weighed to determine daily consumption. Replicated split plot ANOVA and LSD were used to detect differences ($P \leq 0.0001$) in consumption between treatments, replications, and shelterbelts.

RESULTS

Experiment One

We examined 3,541 woody plants (16 species) for signs of animal damage in the 19 one-year old shelterbelts (table 2). Green ash, which was the most common deciduous tree, was found in 90% of the shelterbelts and accounted for 21% of total trees. Common shrubs included tatarian honeysuckle and common lilac. Abundant conifer species included blue spruce and Rocky Mountain juniper.

Of the 3,541 trees planted in spring, 78% were alive the following spring (table 2). Tree survival vaired from 27 to 100% but only 2.3% of total tree mortality could be attributed to animal damage. However, animals caused $\leq$ 20% seedling mortality to Siberian elm, hackberry, and caragana.

Table 2. Occurrence, mortality and animal damage of woody plant species in 19 one year old shelterbelts in Brookings County, South Dakota, 1980.

Species	No. of Trees Examined	% of Total Trees	% Occurrence in shelter-belts	Total Over-Winter Mortality	% Overwinter Survival	% Overwinter Mortality Attributed to Animal Damage	No. of Trees Receiving Sublethal Animal Damage	% of Trees Receiving Animal Damage
Green ash	736	20.7	90.0	63	91.4	4.8	70	10.8C[1]
Honeysuckle	722	20.4	65.0	93	87.1	0.0	31	4.9B
Lilac	420	11.9	35.0	96	77.1	0.0	70	21.6D
Blue spruce	297	8.4	40.0	93	68.7	0.0	3	1.5A
Hackberry	261	7.4	55.0	24	90.8	20.8	71	31.4E
Rky Mtn Juniper	246	6.9	40.0	77	68.7	0.0	0	0.0A
Ponderosa Pine	208	5.9	30.0	131	37.0	0.0	0	0.0A
Amur maple	206	5.8	30.0	16	92.2	6.2	61	32.5E
Dogwood	138	3.9	15.0	100	27.5	3.0	25	68.3I
Cottonwood	59	1.7	20.0	39	33.9	2.6	12	61.9H
Siberian elm	57	1.6	10.0	7	87.7	28.6	5	13.5C
Robusta poplar	53	1.5	20.0	16	69.8	6.2	8	24.3D
Caragana	51	1.4	5.0	10	80.4	20.0	7	20.9D
Eastern red Cedar	31	.9	5.0	3	90.3	0.0	0	0.0A
White willow	31	.9	5.0	4	87.1	0.0	10	37.0F
NW poplar	25	.8	5.0	0	100.0	0.0	12	48.0G
Totals	3,541	100.1		772	78.2	2.3	385	14.5

[1]. Values within columns followed by different letters are significantly different (P < 0.05).

Of trees surviving the first winter, 385 (14%) sustained some form of nonlethal animal damage (table 2). Severity varied by species from 0 to 68%. Of trees receiving nonlethal damage, dogwood and cottonwood received significantly more damage (> 60%) than other deciduous species (table 2). Coniferous species received significantly less clipping injury than deciduous species. Blue spruce was the only coniferous species damaged (1%).

Majority of damage sustained by trees in this study was caused by rabbits and hares. Cottontail rabbits and white-tailed jackrabbits caused 77.8% of the damage to individual trees sampled. Other species responsible for injuring young trees included voles (Microtus spp.) (8.2%), white-tailed deer (6.7%), pocket gophers (Geomys bursarius) (7.0%), and domestic livestock (6.6%). Branch and crown clipping by rabbits was the most common type of injury. Branches were clipped more commonly (170) than either crowns (138) or stems (95).

Experiment Two

Wire fences were successful in preventing rabbits and rodents from clipping or gnawing individual trees. None of the 540 fenced trees were damaged, whereas 21% of the unprotected trees received some type of clipping injury (table 3). The percentage of deciduous trees damaged (43%) was greater than coniferous trees (0%) or deciduous shrubs (21%). Green ash and hackberry received heavy browsing (> 45%) during the first 2 years. Damage between 1, 2, and 3-year old trees did not differ ($P \leq 0.05$), whereas at the 0.10 level of probability, 3-year old trees received less damage (9%) than either 1 or 2-year old trees (26 and 29%, respectively). Two-year old tatarian honeysuckle was damaged more (60%) than common lilac (14%).

Experiment Three

Rabbits clipped green ash branches more than honeysuckle branches in the 5 to 10-year old shelterbelts (table 4). Amount of damage varied by shelterbelt and there was a significant ($P \leq 0.03$) shelterbelt x tree interaction. None of the damage was considered lethal.

Table 3. Rabbit induced clipping injury to 1, 2, and 3-year old shelterbelt trees over winter 1981-82 in Brookings County, South Dakota

Groups	Species within groups	Number of trees											
		One-year-old			Two-year-old			Three-year-old			Total		
		examined	damaged	%	examined	damaged	%	examined	damaged	%	examined	damaged	%
Coniferous tree	eastern red cedar	30	0	0	30	0	0	30	0	0	90	0	0
	blue spruce	30	0	0	30	0	0	30	0	0	90	0	0
	GROUP TOTAL	60	0	0	60	0	0	60	0	0	180	0	0
Deciduous tree	green ash	30	18	60	30	17	57	30	8	27	90	43	48
	hackberry	30	14	47	30	14	47	30	6	20	90	34	38
	GROUP TOTAL	60	32	53	60	31	52	60	14	23	180	77	43*[1]
Deciduous shrub	common lilac	30	5	17	30	4	14	30	2	7	90	11	12
	tatarian honeysuckle	30	9	30	30	18	60*	30	0	0	90	27	30
	GROUP TOTAL	60	14	23	60	22	37	60	2	3	180	38	21
	Age Class Total	180	46	26	180	53	29	180	16	9	540	115	21

1. *Indicates a significant difference (P < 0.05) in number of trees damaged between groups or within a group.

Table 4. Rabbit damage to green ash and honeysuckle in seven 5 to 10 year old shelterbelts in Brookings County, South Dakota

	Mean number of clipping injuries							
	Shelterbelt numbers							TOTAL
Species	1	2	3	4	5	6	7	
Green ash	3.8	4.0	1.0	1.5	4.0	1.9	1.5	2.53A[1]
Honeysuckle	0.7	1.3	0.6	0.4	1.6	1.7	0.8	1.01B
TOTAL	2.2BC	2.6C	0.8A	0.9A	2.8C	1.8B	1.2AB	

[1] Values within totals column or row followed by different letters are significantly different ($P \leq 0.0001$).

Experiment Four

Dried apples were the most selected ration by cottontail rabbits (table 5). Rabbits selected the pelleted ration less than the other diets. Amount of ration consumed varied by shelterbelt and there was a significant ($P \leq 0.02$) treatment x shelterbelt interaction. Significantly less ($P \leq 0.0001$) bait was consumed during the March replicate.

DISCUSSION

Tree species composition of newly-established shelterbelts examined in this study was similar to historic plantings in South Dakota (Walker and Suedkamp 1977, Martin and Vohs 1978) with several exceptions. Green ash and honeysuckle were the dominant woody species planted. However, we observed a reduction in the amount of Siberian elm (> 50% to < 10%) and American elm (> 35% to 0%0) probably because of Dutch elm disease.

Elm trees have a value in shelterbelts by providing nesting, roosting, and foraging sites for passerine birds (Martin and Vohs 1978, Yahner 1982 a,b) and do not appear to be a highly selected winter browse species for rabbits (13.5% damaged in this study). However, 28.6% of elm mortality could be attributed to animal damage, the highest of any species examined, indicating this species may need protection from animal damage.

Our data indicated an increased planting of coniferous trees, which is a positive trend because coniferous species are not preferred forage items for rabbits (McCabe 1945, Swihart and Yahner 1983, this study) or rodents (Barnes and Schaid 1981). In addition, conifers provide winter wind protection for wildlife (Hopkins 1984) and nesting and foraging sites for pheasants, mourning doves (Yahner 1982 a,b; 1983a) and selected passerine birds (Geier and Best 1980; Yahner 1982 a, b; 1983a).

Table 5. Feeding selectivity of cottontail rabbits for 4 rations in 6 shelterbelts in Brookings County, South Dakota

	Mean Gram Consumption						
Ration	Shelterbelt number						TOTAL
	1	2	3	4	5	6	
Dried Apples	109.1	167.6	72.7	62.5	116.9	68.9	99.6A[1]
Corn	106.8	55.4	18.7	25.0	42.3	108.2	59.4B
Oats	67.2	50.0	6.7	0.	92.1	72.5	48.1B
Rabbit Pellets	111.1	1.8	14.2	0.	17.6	6.4	25.2C
TOTAL	98.5A	68.7B	28.1C	21.9C	67.2B	64.0B	

[1] Values within totals column or row followed by different letters are significantly different ($P \leq 0.0001$).

Tree survival during this study was excellent except for dogwood (27.5%), cottonwood (33.9%), and ponderosa pine (37.0%). While cottonwood and dogwood were preferred by rabbits (61.9 and 68.3% damaged, respectively), only a small amount of mortality was a result rabbit browsing (2.6 and 3.0%, respectively). Ponderosa pine was not clipped by rabbits. Low overwinter survival of these species probably resulted from poor nursery stock, planting conditions, maintenance procedures, or a combination of these factors.

Animal damage to trees varied depending upon shelterbelt age and feeding preferences of rabbits but accounted for only a small percentage of overwinter mortality. Shelterbelt locality and rabbit density could also impact the amount of damage received by trees. Of the 3,541 one-year-old trees examined, 2.3% were destroyed due to injury from animals. This amount of damage is substantially lower than animal damage estimates for loblolly pine (Hunt 1968), pacific northwestern forest trees (Black et al. 1979), or selected shelterbelt trees (Baer 1980). While approximately 2% of the total number of trees were destroyed, 20% or more seedling mortality of Siberian elm, hackberry, and caragana was attributed to animal damage.

Young trees are more likely to die from browsing than older trees (Timm 1988) and our data indicated that rabbit damage decreased by the time the trees were 3 years old. Moreover, by the time trees reach 5 to 10-years of age, browsing fails to destroy the tree. Caution should be exercised when making generalities however, because woody plant responses to browsing and their abilities to withstand browsing vary. Several coniferous species, including northern white cedar, die after only light clipping (Aldous 1952), whereas others (e.g. red pine) can tolerate light browsing (Marshall et al. 1955) or even severe and repeated browsing (e.g. green ash), although such damage may result in a scrubby growth form (Parker 1941). Several deciduous species (snowberry, willows) may be stimulated or may exhibit increased vigor when browsed (Willard and McKell 1978, Belsky 1986).

Branch clipping by rabbits was the most common type of damage observed in all shelterbelts. This type of damage is usually not lethal but may result in altered tree growth forms. Rabbit populations vary according to available habitat and the amount of damage presumably varies as a function of rabbit density, amount of forage available, and feeding selectivity of individual animals. Differences in amounts of clipping injury between shelterbelts recorded in the 5 to 10-year old plantations were probably a result of varying rabbit densities, associated habitat variables, and availability of alternative forage sources. These data indicate that rabbits are the dominant vertebrate pests in newly-established shelterbelts as suggested by Timm (1988) but the intensity of damage varies geographically and may be related to woody species planted (Geis 1954, Baer 1980, Swihart and Yahner 1983).

Rodent damage was not severe in this study (8.2%). However, vole populations are highly cyclic (Keith 1974) and during peak densities, voles may cause extensive damage (Littlefield et al. 1946, Cayford and Haig 1961, Sartz 1970). Rodent populations were not measured in our study. Rabbit and rodent damage to highly susceptible woody species can be effectively controlled using fences or plastic tree guard tubes (Baer 1980, this study).

Feeding preferences of rabbits in the 1, 2, and 3-year old shelterbelts varied, but generally deciduous trees were selected first, deciduous shrubs were secondarily preferred, and coniferous species were mostly avoided. Even in the older shelterbelts (5 to 10-year age class), rabbits selected a deciduous tree over a deciduous shrub. The amount of damage to specific woody species also varied during each study. In this first study, 10% of the green ash and 5% of the honeysuckle trees were injured, whereas in the second experiment up to 60% of the unfenced trees of both species were injured. The amount of damage incurred by the coniferous species, hackberry, or lilac were similar among studies.

The reason rabbits and rodents select certain tree species and why it varies geographically is not clearly understood. Sweetman (1944, 1946, 1949) reported that in Massachusets rabbits preferred browsing dogwood, cottonwood, and willows similar to our results. However, Swihart and Yahner (1983) and Baer (1980) found that jackrabbits in Minnesota and South Dakota prefer fruit trees; cottontails selected barberry, snowberry, serviceberry, and elms, species occurring in limited abundance in shelterbelts. This feeding selectivity by hares and rabbits may be related to the presence of secondary plant compounds. Most coniferous species planted in shelterbelts contain resins, terpenes, volatile oils, or other secondary plant compounds, which may act as a natural deterrent to browsing (Bryant and Kuropat 1980, Sinclair et al. 1982, Tahvanainen et al. 1985).

Efficacy of providing alternate food for rabbits to alleviate damage to trees will vary due to a variety of factors including rabbit density, proximity to other available habitat, and tree species available for browsing. Our data showed that forage consumption by rabbits varied between shelterbelts which indicated differences in rabbit populations within a given area, availability of alternative forage sources, or feeding selectivity of rabbits. Consequently, this technique may not work under all circumstances. The data indicate if alternative feeding is the preferred control option, January and February are the most appropriate times because low quantities of bait were eaten in March. Low consumption in March could be attributed to natural rabbit mortality by this time or to the reappearance of natural forage. Our data indicated that rabbits preferred dried apples and avoided pelleted ration. Dried apples would be expensive and difficult to obtain; whereas, corn or oats are readily available and are probably more cost effective.

MANAGEMENT RECOMMENDATIONS

Data collected in this study indicate that certain tree species are highly susceptible to rabbit browsing. However, since damage occurred primarily to 1 and 2-year old trees, not all species were heavily browsed, and fencing provided maximum protection from browsing, we recommend that some type of protective device be placed around highly preferred tree species for several years. We also encourage increased planting of coniferous tree species because they do not receive damage from rabbits and they provide benefits to wildlife. We also recommend using woody species that are not highly preferred by rabbits where rabbit populations are high. If providing an alternative forage source is the management option selected, we suggest of the foods tested, using corn or oats during January or February.

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Managing Damage to Alfalfa Caused by Plains Pocket Gophers[1]

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Plains pocket gophers (Geomys bursarius) may reduce yields of grasslands and alfalfa fields 21 to 49%. This represents a significant economic liability. Numerous means of reducing pocket gopher densities have been implemented. Some of our current methods to control pocket gophers are being seriously challenged, thus necessitating new ways of managing damages caused by this mammal.

INTRODUCTION

The discipline of wildlife management that deals with problem animals, or damaging animals, is beset with numerous problems. Often the most direct means of lessening problems or damages is through animal removal. Frequently that is accomplished by killing the offending animal or reducing the population of that species. There are numerous alternatives to animal removal including habitat alteration, repellents, fencing, and various cultural practices.

Despite the well-reasoned (to problem-animal managers, at least) pleas to justify animal removal, many segments of society have registered protests to this approach. Their protests run the gamut from being not cost effective to being not humane or in violation of an animal's right to exist to upsetting the natural balance (which now includes chemical contamination of our earth).

One way to deal with these challenges is to direct our efforts to nonlethal methods. This thought is certainly not new. However, much of our thinking in this field has been vertical. We have tried to devise better methods of killing animals. We have strived to make our lethal agent highly species-specific, short-lived in the environment, and incapable of causing secondary poisoning. I suggest that we try more horizontal thinking as we strive to come up with new ways to cope with problem animals, or animal damage problems.

Most recently we have had another factor confound our difficulties. Or, perhaps this has enhanced our opportunities. That is the Agriculture Productivity Act which was passed by Congress in 1985, as a part of P.L. 99-198, The Food Security Act. This act provides the authority to conduct education programs and research in low-input, sustainable agriculture (LISA).

LISA has several objectives including increasing on-farm profits to maintaining the environment. The program will build on Integrated Pest Management (IPM) and crop rotation practices. The outcomes expected of LISA are reduced input costs to the farmer, erosion control, and pollution abatement resulting from decreased fertilizer and pesticide use. This is where we have a problem or an opportunity.

The objectives of my paper are to document that pocket gophers do cause damage to forage crops, that this loss is significant economically, and that there may be new ways to control damages caused by pocket gophers. The new ways are not always new, but they are untested and could incorporate theoretical aspects as well as anecdotal means.

YIELD REDUCTION ATTRIBUTED TO THE PRESENCE OF POCKET GOPHERS

Foster and Stubbendieck (1980) investigated the effects of plains pocket gophers on forage yields on rangelands in western Nebraska. Their findings indicated that pocket gophers reduced yields from 21 to 49% on four different sands and silty range sites. The lowest reduction occurred on the poorest range site. Pocket gophers also reduced range condition (% of climax) on all range sites. And there was a reduction in perennial grasses on all sites where gophers were present with a concomitant increase in annual grasses and both annual and perennial forbs.

Luce et al. (1981) documented that plains pocket gophers reduced yields of dryland alfalfa 43 to 46% in southeastern Nebraska. Alfalfa plant density also decreased, but other plant species increased when gophers were present. This offset the loss of yield somewhat but total forage yields still were 37-38% less when gophers were present.

Hegarty (1984) investigated the effects of plains pocket gophers on irrigated alfalfa and hay meadows in the Nebraska Sandhills. He found that yields were reduced an average of 30% on hay meadows but only 17% on the irrigated alfalfa. Again increaser or invader vegetation was associated with the presence of pocket gophers.

The above studies in Nebraska have been corroborated by other researchers. Fitch and Bentley (1949) reported a 25% reduction in forage on foothill rangelands in California when pocket gophers were present. The pocket gopher was the smaller Thomomys

[1]Paper presented at the Ninth Great Plains Wildlife Damage Control Workshop. [Colorado State University, Fort Collins, April 17-20, 1989].

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bottae. Alsager (1977) noted that rangeland yields increased 16% after T. talpoides were controlled on rangelands in southwestern Alberta, Canada. Finally, Reichman and Smith (1985) found a one-third reduction in plant biomass directly over plains pocket gopher tunnels compared to adjacent areas. It can be safely stated that the presence of pocket gophers will reduce vegetation yields. The economics of controlling pocket gophers have been modeled by Case and Timm (1984). Their model mandates the economics of alternative control techniques compared with no control. However, many improvements still need to be made in our data base.

It is important to know why yields are less when pocket gophers are present. Obvious causes are direct consumption, burial of vegetation, and changes in species composition. In addition plant vigor likely is affected which can influence its competive capabilities. Perhaps this is why yield reductions, in irrigated alfalfa, where pocket gophers were present, were not as severe as on dryland habitats. Finally, pocket gophers also benefit plant production by increasing water infiltration, reducing soil compaction by their tunneling, adding fertility to the soil by their feces and buried vegetation, and by reducing plant density. How can we use this information to minimize adverse effects of pocket gophers?

POCKET GOPHERS AND BELOWGROUND BIOMASS

It is obviously very energy demanding to move through a medium as dense as soil. Thus, if gophers are prudent in their movements, they should dig less in rich habitats and more so in poor habitats, assuming that gophers dig primarily to obtain food. However, Sparks and Anderson (1988) and Anderson (1987) failed to detect any correlation with Geomys bursarius burrowing and belowground resource availability. Cameron et al. (1988) also concluded that burrow systems of G. attwateri were not adaptive to resource availability. Factors that the above authors noted to influence pocket gopher burrowing were the size of the animal and bulk density of the soil.

Why gophers dig so much is yet to be determined. Tunberg et al. (1984) noted that pocket gophers readily invade and utilize tunnels that have been abandoned or are otherwise not used. This may in part be related to locating a mate.

POCKET GOPHERS AND OTHER ALFALFA VARIETIES

Alfalfa with fibrous root systems, such as Spredor II, have great winter hardiness, however, this is accompanied by a yield loss. This probably explains why this variety is not used often where cold tolerance is not critical. By the fourth year the yield is only about 80% of the tap rooted variety, Wrangler.

On the other hand, each time a root of Spredor II is broken or damaged, it will sprout a new shoot. What will be the impact of short term belowground herbivory on yields of Spredor II? Could it be that the presence of pocket gophers will actually increase the above ground yield?

Even without compensatory yield increases, the fibrous rooted variety will survive with some belowground herbivory while the tap-rooted variety will die if the tap root is consumed by pocket gophers. Also, with partial feeding, plant vigor should not be as adversely affected by herbivory and the fibrous variety could maintain its competitiveness.

MANAGEMENT IMPLICATIONS

Public concern about chemicals in the environment and general concern to increase the profitability of the agricultural community have resulted in legislation that will influence damage control operations. We need to expand our data base and expand our thinking to include other control methods. With LISA there will likely be more use of crop rotations and extensive use of alfalfa in those rotations. The frequency of rotation, alfalfa variety, and other benefits from rotation such as reduced insect and disease loss to crops all need to be included in an analysis of damages and methods to control those damages.

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Kansas Attitudes on Prairie Dog Control[1]

Charles D. Lee[2] and F. Robert Henderson[3]

Abstract.--In Kansas prairie dog management is primarily determined by private individuals and local government agencies. We conducted a mail survey of 350 affected landowners as a means to evaluate the effectiveness of current prairie dog control. The same survey was also sent to 350 randomly selected state residents within the general prairie dog range. We evaluated people's perceptions of prairie dogs, the effectiveness of control methods, costs of control, and reasons for poor response to control techniques. Results indicate people that have previously been involved in prairie dog control on lands they manage have different opinions about prairie dogs than general residents.

INTRODUCTION

In Kansas prairie dog management is primarily determined by private individuals and local government agencies. In 1901 and 1903, the Kansas legislature passed laws (K.S.A. 80-1201, 1203) authorizing townships to conduct prairie dog eradication programs and provide funds for Kansas State Agricultural College to hire a field agent to "direct and conduct experiments for the purpose of destroying prairie dogs and gophers" (Lantz 1903). In recent years seven counties have invoked "Home Rule" to take over authority for prairie dog control from the townships and impose mandatory control requirements on landowners. This came about mainly because of increasing prairie dog numbers and disputes over the problems created when prairie dogs dispersed into surrounding pastures.

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Some counties have gone to an operational program where the landowner is first given the opportunity to control "his" prairie dogs and if he fails to do so it is done by the county at landowner expense. In several counties the county weed supervisor is given prairie dog control responsibility in the winter. Other counties contract with commercial pest control applicators to conduct the control program. If the landowner refuses to pay the costs, the costs may be extended to the property and extended on the property's tax roll.

Township boards and county commissioners in some cases mandate prairie dog elimination. A few landowners are being forced to eliminate prairie dogs on their acreage even though they may like and protect the prairie dogs.

In Kansas over 97% of the land is in private ownership. In Wallace County, Kansas, a Cooperative Extension Service (CES), estimate indicated over 14,000 acres inhabited with prairie dogs in 1979. CES again surveyed that county in 1988 and determined that there are less than 300 acres inhabited by prairie dogs. This type of reduction in acres has not occurred in other counties that have a county-wide control. However, Wallace county has had some very hardworking,

persistent and dedicated employees involved in the prairie dog control program for the last 10 years.

Estimates of prairie dog acreage in Kansas are not very precise. Some states, including Kansas, are planning on conducting prairie dog surveys to locate sites for possible black-footed ferret reintroduction. Kansas Cooperative Extension Service surveyed eight counties for prairie dog colonies in Kansas in 1988. The purpose of this survey was, in part, to obtain bench mark data to measure prairie dog expansion 10 to 20 years in future as a result of CRP native grass plantings now taking place. This survey was conducted using Kansas Department of Revenue aerial photographs. These high quality photo's (1:4800) were accurate in locating prairie dog colonies. The photographs were taken in the spring of 1986 and colonies may have changed since then. Some researchers have noted inaccuracies in relying on aerial photos as population indicators (Bishop and Culbertson 1976 and Cheatheam 1973). However, there are not other known methods that involve less expense and offer at least trend data as accurate as this method. Kansas Department of Revenue plans to have photographs available on a 5 year rotation.

METHODS

KSU Extension conducted a mail survey in the fall of 1988 to gather information on Kansan's attitudes on prairie dogs. The survey was sent to 350 landowners who had previously received a permit from Kansas Wildlife and Parks to fumigate prairie dogs. This permit is required by Kansas law (K.S.A. 32-158). About 350 general residents in the prairie dog range were also mailed survey forms. Response rate was good with a 48% return from the landowners with previous permits. Only 22% of the general residents responded to the survey. No follow-up attempts were made to collect information.

RESULTS

The two segments of populations that were surveyed viewed prairie dogs differently. It is interesting to note that 95% of the people who had prairie dogs on their range view them as pests, and 78% of the general residents that responded believed prairie dogs were pests to rangeland. This contrasts with some views that prairie dogs are not as destructive to rangeland as once believed and in some ways may be beneficial to rangeland (O'Meilia et al 1982 and Uresk 1985).

Only 5% of the people with prairie dogs viewed them as being ecologically important but, 18% of the random sample had this belief. Lovaas (1973) reported that prairie dogs are probably the most popular wild animal in the National Park areas of the Great Plains.

The re-introduction of the black-footed ferret is also an issue that concerns those involved with prairie dog management.

About 1/2 of those people who responded to the survey would like to see black-footed ferrets re-established in the wild. There was no significant differences between the two groups of Kansans. Comments about ferrets ranged from "I don't know much about ferrets, but sure haven't seen any good in prairie dogs" to "I'd go for the ferrets if they would wipe out pocket gophers." We believe a great deal of educational effort is needed so that public attitudes can change. Neither side in this problem seem to be embracing knowledge derived from scientific studies. It may be too late to bring about a change in public thinking before environmental factors start having detrimental effects on not only prairie dogs, but man too.

There are many different control methods being utilized in prairie dog control programs. In Kansas more people that responded to the survey used fumigants than any other method reported. Fumigants have the most detrimental effects on any ferrets that may be present, however, we believe the black-footed ferret no longer exists in Kansas.

Zinc phosphide treated oats are now most often recommended as a control method and would have the least detrimental effect upon the black-footed ferret. Yet, only 9% of the respondents indicated they used that product.

Products that were reported to be used occasionally but are not registered for prairie dogs include gasoline, propane, anhydrous ammonia, poison peanuts, larvacide, and chloropicrin.

Sometimes lack of success in control methods by individuals is cited as a reason for county-wide control efforts. This survey indicates 53% of the individual respondents achieved a success rate greater than 90%. Reasons for lack of good success rates varied with the type of

control program used, but 39% of the respondents believe the prairie dogs migrated into their land after they had controlled them.

Some thought could be given to an overall prairie dog management plan within given areas of the Kansas prairie dog range. Public monies could be used to keep prairie dogs within tolerable limits and at the same time demonstrations along with an educational program could be used to bring about better grazing management which would tend to limit prairie dog expansion.

If the general public wants prairie dogs at this particular point in time a cooperative plan with affected landowners needs to be started.

The "boom and bust" control programs are resulting in a reduction in prairie dogs, overgrazing, and no possible hope for restoring black-footed ferrets on private land in Kansas. This would seem to indicate support for control efforts over a large area as opposed to each individual landowner controlling prairie dogs on his property. But the question is, will the objective be "control" or eradication?

ECONOMICS

Costs to control prairie dogs ranged from $3.00/acre to over $100/acre. The average cost estimated by 114 respondents on this question was $32.84/acre. The costs reported by users are higher than previous researchers have reported (Collins et al 1984).

The value of the grass lost due to prairie dogs differed widely among groups. Those people that had permits claimed prairie dogs consumed $30.05 worth of grass per acre and the general resident believed prairie dogs would consume $6.71/acre.

Shooting as a Control Method

Sometimes shooting of prairie dogs is recommended as a control method (Knowles, 1988). In Kansas, we in Extension often get requests for places to hunt.

Of the 87 of the respondents who allowed shooting of prairie dogs only 4 landowners wanted their land on a list as a place that allowed hunting of prairie dogs. Just 8 landowners wished to have their land listed as a place to shoot prairie dogs for a fee. The recommendation of shooting of prairie dogs does not seem to be a viable alternative for Kansas prairie dog managers who must rely on personal contacts to fulfill the need of recreational hunting of prairie dogs.

SUMMARY

People attitudes play a large role in prairie dog management. This survey showed a majority of Kansans consider prairie dogs as pests and not ecologically or recreationally important. If the public does not consider the prairie dog as a valuable part of our natural resources, its future looks bleak. Kansans report excellent success in controlling prairie dogs. Since over 97% of Kansas is held in private lands, governmental agencies concerned with management of prairie dogs may have little to do.

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Effects of Two Prairie Dog Rodenticides on Ground-Dwelling Invertebrates in Western South Dakota[1]

Michele S. Deisch,[2] Daniel W. Uresk,[3] and Raymond L. Linder[4]

Abstract.--Immediate and long-term effects of 3 rodenticide treatments on nontarget invertebrates were evaluated on prairie dog colonies. Immediate impacts indicated zinc phosphide reduced ants, strychnine alone reduced wolf spiders, and prebaited strychnine had no impacts. Long-term changes showed increases in wolf spiders and ground beetles and densities were contributed to biotic and abiotic habitat alterations due to lack of prairie dog activities. Among comparisons for efficacy, zinc phosphide was more efficacious at immediately reducing ant densities than either strychnine treatment; long term impacts for insects in general were minimal.

INTRODUCTION

Immediate and long-term effects of rodenticides on nontarget invertebrates has not been fully evaluated. Many rodenticides are nonspecific and a margin of safety to nontarget invertebrates is often overlooked by applicators when selecting toxic baits. Control of black-tailed prairie dogs (Cynomys ludovicianus) in western South Dakota provided an opportunity to study rodenticide impacts on nontarget invertebrates and to compare efficacy of 3 rodenticide treatments.

Prairie dogs create niches for invertebrates in rangeland ecosystems (Wilcomb 1954, Koford 1958, Smith 1967, O'Meilia et al. 1982, Agnew 1983). For example, prairie dogs act as ecosystem regulators by maintaining habitat patches of diverse vegetation (Detling and Whicker 1987) suitable for invertebrates that are associated with bare soils, sparse vegetative cover, and short-grass habitats. Invertebrate habitat provided by burrows is disturbed when prairie dogs are poisoned and prairie dog activity ceases. Burrows are no longer maintained, soil erodes into the hole and vegetation recaptures mounds (Potter 1980). It is unknown how induced changes on short-grass habitat effects invertebrates associated with prairie dog burrows.

This study assessed immediate and long-term responses (1 year after rodenticide application) of invertebrate densities on poisoned prairie dog towns. Secondly, efficacy of zinc phosphide-with prebaiting, prebaited strychnine, and strychnine alone were compared for reduction of nontarget invertebrates. Information will provide further understanding of prairie dog town ecology and management guidelines for minimizing nontarget invertebrate losses due to prairie dog rodenticides.

STUDY AREA

The study was conducted south of Wall and east of Rapid City on Buffalo Gap National Grasslands and in the Badlands National Park of western South Dakota. Vegetated table top buttes and gently rolling mixed grasslands scattered throughout the Badlands formations characterize much of the area and support prairie dog towns (See Deisch 1986 for complete description).

The National Grasslands located in Conata Basin were grazed by cattle at stocking levels set by the Forest Service. American bison (Bison bison) were located in Badlands National Park but cattle were absent.

METHODS

Invertebrates were sampled with pitfall traps (Greenslade 1964, Gist and Crossley 1973). Eighteen permanent sites were established on 15 prairie dog colonies. Metal cans (15 cm x 15 cm) lined

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with plastic buckets were buried flush with soil surface. Pitfall traps were arranged within a grid design with 10 m spacing. Traps were opened (lid removed) for 4 consecutive nights (196 trap nights/session) on each site. Trapping sessions were from May through October of 1983 and May through August of 1984. Mean of each taxa per trap session was estimated for relative density.

Immediate impacts of rodenticides were sampled on each site 1 week before poison application in September 1983. Posttreatment counts were taken the fourth day after rodenticides were applied. Long-term impacts of rodenticides were evaluated from data collected during September 1983 and all 1984 trap sessions. Rodenticides were not applied in 1984.

Rodenticides and Bait Application

Steam-rolled oats used for prebait (4 g) and poisoned bait (4 g) were formulated at U.S. Fish and Wildlife Service Pocatello Supply Depot. A 2.0% by weight active zinc phosphide and 1.5% Alcolec S (American Lecithin Co., Inc.)[a] adhesive were applied to oats. Strychnine alkaloid was applied to oats as 0.5% by weight. Nontreated oats were applied as prebait for zinc phosphide and for 1 strychnine treatment. Active rodenticides on oats were applied 3 days after prebaiting. Both prebait and rodenticides were applied to large areas from bait dispensers affixed to Honda ATV's (Schenbeck 1982). Smaller areas were poisoned on foot and bait was distributed onto mounds with teaspoons.

Statistical Analysis

Each rodenticide was evaluated for effects on nontarget invertebrates by comparing the change of mean relative density on each cluster of treated sites with the change observed on respective control sites. Five comparisons through time included immediate impacts (September 1983) measured between pretreatment and posttreatment poisoning. The remaining 4 comparisons were differences in years from pretreatment (1983) to posttreatment (1984). When a significant correlation existed between pretreatment and posttreatment observations, analysis of covariance was used (Deisch 1986, Uresk et al. 1987) and if non significant, subtraction (Green 1979) was used.

Comparisons among rodenticides for efficacy were produced by forming pairwise contrasts of individual rodenticide treatments. Randomization procedure was used to estimate statistical significance of various contrasts (Edgington 1980, Romesburg 1981, Uresk et al. 1986, Uresk et al. 1987). Rejection of any rodenticide impact (Type II error) to nontarget invertebrates was considered more serious than potential incorrect acceptance of a significant treatment effect (Type I error) (Tacha et al. 1982).

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[a]Reference to trade name does not imply endorsement of product.

After significant ($P=0.10$) treatment differences were detected, Type II error protection was produced by testing each contrast individually. Type I error protection was afforded by testing for a significant ($P=0.10$) individual contrast of treatment differences with analysis of variance or covariance (Carmer and Swanson 1973).

Individual contrasts were considered biologically significant at $P=0.20$. Although an alpha of 0.20 is not a standard level of significance, it is becoming more accepted for ecological field studies (Hayne 1976). The number of sites available for this study produced a power of 0.80. This was an acceptable combination of Type I and Type II error protection (Carmer 1976) and allowed for reasonable biological inferences to be drawn from the data.

RESULTS

Five invertebrate classes were collected: Insecta, Arachnida, Chilopoda, Diplopoda, and Crustacea. The 7 most abundant invertebrate families used in statistical analysis were spider mites (Tetranychidae), ants (Formicidae), wolf spiders (Lycosidea), crickets (Gryllidae and Gryllacrididae), ground beetles (Carabidae), dung beetles (Scarabaeidae), and darkling beetles (Tenebrionidae).

Immediate Effects of Rodenticides

Zinc phosphide immediately reduced ant densities on treated sites (fig. 1). Spider mite, cricket, wolf spider, ground beetle, darkling beetle, and dung beetle densities were not immediately affected by zinc phosphide. There were no immediate effects of prebaited strychnine on the 7 invertebrate families (fig. 2). Only wolf spiders were immediately affected by strychnine (fig. 3). Densities decreased 13% on treated sites.

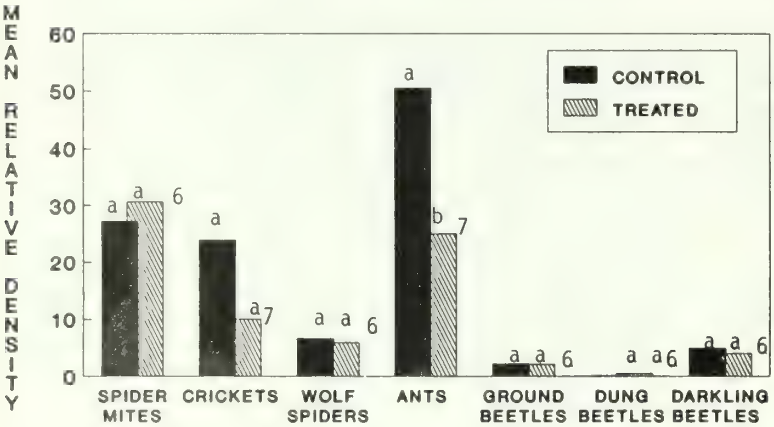
Long-term Effects of Rodenticides

Wolf spiders and ground beetles showed increases after one year on zinc phosphide and strychnine with pre baiting respectively (Deisch 1986). Other insects were variable among rodenticide treatments with no consistant patterns. Generally long-term impacts were minimal for these insects.

Efficacy of Rodenticides

Comparisons of efficacy among 3 rodenticide treatments were made when an immediate or long-term treatment effect was detected. Zinc phosphide was more efficacious at immediately reducing ant densities than either strychnine treatment. Other efficacy comparisons showed no significant differences in reductions of nontarget invertebrates. There were no efficacy differences between strychnine and prebaited strychnine treatments for immediate impacts. Long-term efficacy effects were extremely variable and no consistent pattern in rodenticide effectiveness was detected. Long-term "effects" were not directly related to rodenticides, but more to habitat changes (Deisch 1986).

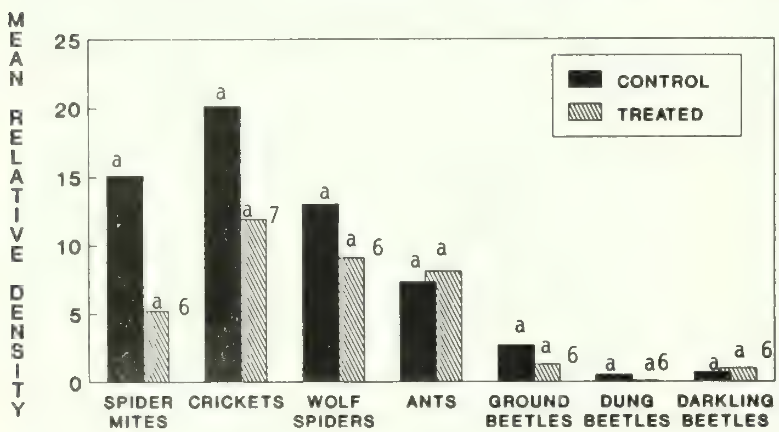
Figure 1.--Comparisons of invertebrate means/196 trap nights on sites treated with zinc phosphide and control sites, September 1983. Adjusted means (bars) were estimated by analysis of covariance.



[6]Means followed by same letter were not significant at P=0.20 after F-protection at P=0.10. Pretreatment (covariate) means were used to adjust posttreatment means for statistical comparisons.

[7]Posttreatment minus pretreatment was used to adjust data for statistical analysis.

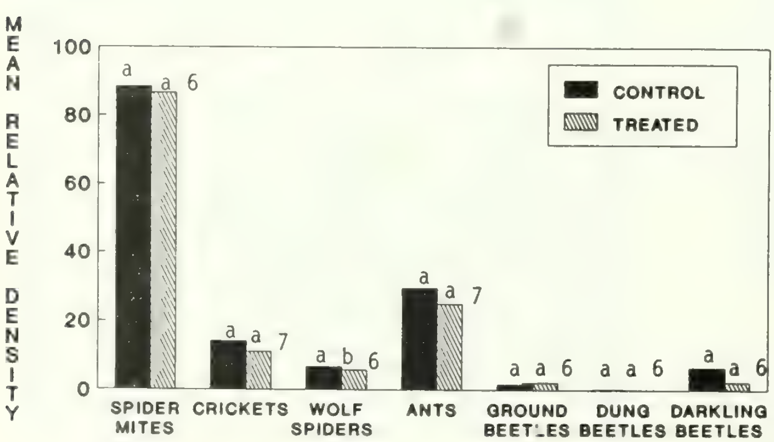
Figure 2.--Comparisons of invertebrate means/196 trap nights on sites treated with prebaited strychnine and control sites, September 1983. Adjusted means (bars) were estimated by analysis of covariance.



[6]Means followed by same letter were not significant at P=0.20 after F-protection at P=0.10. Pretreatment (covariate) means were used to adjust posttreatment means for statistical comparisons.

[7]Posttreatment minus pretreatment was used to adjust data for statistical analysis.

Figure 3.--Comparisons of invertebrate means/196 trap nights on sites treated with strychnine and control sites, September 1983. Adjusted means (bars) were estimated by analysis of covariance.



[6]Means followed by same letter were not significant at P=0.20 after F-protection at P=0.10. Pretreatment (covariate) means were used to adjust posttreatment means for statistical comparisons.

[7]Posttreatment minus pretreatment was used to adjust data for statistical analysis.

DISCUSSION

Immediate effects

Ecological literature lacks supportive information on direct and indirect effects of zinc phosphide and strychnine on nontarget invertebrates. Invertebrates will carry off and consume poisoned grain distributed for rodent control (Marsh 1962). Invertebrates on prairie dog towns that consume seeds were immediately effected by rodenticidal grain.

Ants were immediately reduced on zinc phosphide sites. Harvester ants (Pogonmyrex spp.) in western states feed principally on seeds and can be exterminated with poisoned grain (Furniss and Carolin 1977). Strychnine alone showed immediate reductions of wolf spider relative densities. It is questionable that strychnine directly reduced wolf spiders since these arachnids do not consume seeds (Lowrie 1973, Milne and Milne 1980). However, it is suggested that strychnine influenced the food base of the predatory spider.

Spider mites, crickets, darkling beetles, ground and dung beetles were not affected by the 3 rodenticides because of their food preference (Borror and White 1970, Milne and Milne 1980). Spider mites are equipped with piercing mouth parts for sucking plant juices and usually feed on live green vegetation. Crickets do not depend upon grain for their survival and feed on plant foliage, seedlings, dead and dying insects, hair, hide and carrion. Darkling beetles are detritivores but will consume small amounts of seeds (Kramm and Kramm 1972). Ground beetles are voracious predators. Dung beetles are scavengers and recycle dung, carrion, and decaying vegetative matter (Kramm and Kramm 1972).

Long-term impacts

In this study very few long term impacts occurred. Wolf spider densities increased the year following treatment with zinc phosphide and an increase ground beetles occured on the strychine treated areas. Vegetation height on treated prairie dog towns increases after elimination of prairie dogs (Klatt 1971, Potter 1980). Wolf spiders are active on soil surface and seek cover under vegetation and debris to hunt (Lowrie 1973). Change in vegetation structure provided greater cover and prey diversity (Murdock et al. 1972).

Dramatic ecological changes occur on prairie dog towns once these rodents have been poisoned and eliminated. Changes in plant communities (Uresk 1985), lack of suitable prairie dog borrows, and lack of continual soil mixing by prairie dogs, can influence insect density and diversity (Koford 1958).

Invertebrates have been overlooked in most ecological studies that pertain to nontarget losses due to rodenticides. These small fauna are important components of rangeland ecosystems (Hamm 1972, HeWitt et al. 1974, Agnew 1983, Sieg et al. 1985). Insects and archnids often make up a large percentage of animal protein matter in diets of mammal species that are associated with prairie dog towns. These include swift fox (Vulpes velox) (Uresk and Sharps 1986), burrowing owl (Athene cunicularis) (MacCracken et al. 1985), northern grasshopper mouse (Bailey and Sperry 1929), deer mouse (Flake 1973), and other insectivorous mammalian and avian species.

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Plant Compositional Change in a Colony of Black-Tailed Prairie Dogs in South Dakota[1]

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Abstract.--Peak season multi-species cover of vegetation and burrow mound density were estimated for 3 years along a transect that ran from the geometric center of a black-tailed prairie dog (Cynomys ludovicianus) colony, to its edge. The forb dominated core of the colony expanded 25 m in radius during the study, while plant composition changed dramatically in a small (<0.3 ha) zone midway between the edge and the core. We determined that year to year functional increases in multi-species canopy cover, described by the natural growth function (R^2=0.72, P<0.001), occurred only after shortgrasses were reduced below 75% cover. The density of burrow mounds was positively correlated to compositional change (r=0.58; P<0.01). We observed that burrow mounds provided early sites for the eatablishment of forbs. However, after the canopy cover of shortgrasses receded below 75% (in this location, probably from 4 to 7 years after initial inhabitancy by prairie dogs), extensive compositional changes occurred between burrow mounds.

INTRODUCTION

Largely because of the influence that the black-tailed prairie dog (Cynomys ludovicianus Ord) exerts on trend in rangeland vegetation, the species has been a target of extermination or intensive control since the early 1900's (Merriam 1902, Schenbeck 1982, Uresk 1987). Plant succession within colonies has been described as consisting of the initial disappearance of perennial grass cover, followed by an increase in shortgrasses (Bonham and Lerwick 1976), and an eventual increase and dominance by annual forbs and dwarf shrubs (Koford 1958, Garrett et al. 1982, Coppock et al. 1983, Archer et al. 1987). The pattern of plant composition appears to recapitulate colony expansion, i.e. as prairie dog colonies expand outward, a forb-dominated community follows. The objective of our study was to determine the extent, rate, and pattern of prairie dog induced changes in plant composition within a colony on mixed-grass prairie habitat.

MATERIALS AND METHODS

Study Area

The study was conducted in Badlands National Park, in southwestern South Dakota, in a colony of black-tailed prairie dogs situated in mixed-grass prairie, north of the edge of the White River Badlands. Vegetation of the area is wheatgrass-grama-buffalo grass type described by Kuchler (1975). Occurrence of flora and fauna in the area is described by Agnew et al. (1986). Descriptions of soils, topography and climate are available in Cincotta et al. (1987), and Uresk and Schenbeck (1987). The prairie dog colony selected was <10 years old at the beginning of the research. It was located approximately 1 km north of the valley ridge, or "wall", that marks the northern extent of

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the White River Badlands, about 16 km. south from Wall, South Dakota. When prairie dogs first became established, the location was a privately owned horse pasture. Livestock Bison (Bison bison) grazed on the colony, during the study, however livestock did not utilize the area.

Changes in Plant Composition

The colony was sampled once annually, from 1981 to 1983, during the peak period for biomass of ungrazed vegetation (the last week in July and first week in August). In order to intersect the full range of vegetation, the canopy cover of individual plant species was evaluated along three parallel center-to-edge transects, which we have collectively termed a profile. Five meters apart, the three replicates traced straight lines from the origin of the colony (the oldest burrows, pinpointed by the former property owner) near the geometric center of the colony, to points (525 m away) on the western edge of the colony.

Along the profile, we chose an interval of 25 m to separate sampling sites, S (S=0,1,2,..., 21), inside the colony (on-colony). At each S, we established three sampling transects, one on each replicate of the profile. To quantify local plant composition without prairie dogs, we extended the profile 50, 75, and 100 m beyond the colony, thus establishing a site, S', of nine sampling transects outside the colony (off-colony). Each transect was 29 m long, along which thirty (50 cm by 20 cm; 0.1 m^2) quadrats were placed, 1 m apart. Canopy cover per species was estimated by recording the appropriate class, from six possible cover classes (Daubenmire 1957), for each plant species present in the quadrat.

We defined plant composition as the canopy cover of plant species encountered, i.e. multi-species cover. To compare multi-dimensional data (on-colony vs off-colony) with a computer algorithm for the multi-response permutation procedure (MRPP; Berry and Mielke 1983), we reduced the data to 20 plant species (from 75 encountered) by selecting the twenty species with the highest maximum cover among pooled sites. These species (common and scientific names according to Van Bruggen 1985) were: western wheatgrass (Agropyron smithii Rydb.), red threeawn (Aristida purpurea Steud.), dwarf sagebrush (Artemisia cana Pursh), Aster falcatus Lindl., Japanese chess (Bromus japonicus Thunb.), cheat grass (B. tectorum L.), buffalo grass (Buchloe dactyloides (Nutt.) Engelm.), Carex eleocharis Bailey, Chenopodium strictum Roth, horseweed (Conyza canadensis (L.) Cronq.), six-weeks fescue (Festuca octoflora Walt.), summer cypress (Kochia scoparia (L.) Schrad.), poverty weed (Monolepis nuttalliana (Schultes) Greene), buckhorn (Plantago patagonica Jacq.), Russian thistle (Salsola iberica Sennen & Pau), tumble-grass (Schedonnardus panniculatus (Nutt.) Trel.), cut leaf nightshade (Solanum triflorum Nutt.), scarlet mallow (Sphaeralcea coccinea (Pursh) Rydb.), sand dropseed (Sporobolus cryptandrus (Torr.) A.Gray), and prostrate vervain (Verbena bracteata Lag. & Rodr.). All species with a cover value greater than 2.0% were retained, including nearly all local major forage species for livestock (Uresk 1986) and prairie dogs (Uresk 1984, Fagerstone et al. 1981). The absence of blue grama (Bouteloua gracilis (H.B.K.) Griffiths) from this list is due both to its paucity on this site and our inability to distinguish it from buffalo grass when the grasses were in a clipped condition.

The difference in cover between S and S', was calculated as the euclidean distance measure between multi-species means:

$$D_s=\left(\sum_{i-1}^{20} (C_{is}-C_{is'})^2\right)^{0.5}$$

where C_i is the cover of a species.

To test the null hypothesis, $H_o:D_s=0$ ($n_s=3$, $n_{s'}=9$), we used a permutation technique, MRPP (Mielke 1986, Mielke et al. 1981, Mielke et al. 1976). MRPP utilizes the sum of the euclidean distances (weighted for group size; Berry et al. 1983), d, between all possible within-group pairs to express concentration within a particular mutually exclusive, exhaustive grouping with group sizes $g_1,g_2,...,g_m$ (Berry et al. 1983; for detailed example, see Zimmerman et al. 1985). The null hypothesis actually proposed with MRPP, that all permutations of $g_1,g_2,...,g_m$ are equally likely, is tested by: (1) ordering the computed values of d, (2) locating the relative position of the statistic on the list and (3) determining the P-value as the proportion of all values of d less than or equal to the observed value of the a priori grouping. We assumed that the group mean at each S was different from S' when the P of more extreme distances was ≤ 0.05. The full set of species encountered in sampling was used in this computation.

Plant composition was further described by calculating the ratio of forb to grass cover at sampling sites. Forbs included all broad-leaved plants. Grasses included species from the taxonomic families of Poaceae and Cyperaceae (sedges). All species encountered during sampling were included in this computation.

Rate of Compositional Changes

Since we did not know the exact time of prairie dog establishment on all points along the profile, we calculated a growth rate relative to the previous year's state (Green 1979). Thus, we assumed that D[t+ t] was a function of D[t], where t equaled 1 year, and t was peak season during each of the first two study years. Since D has a finite upper limit (the maximum possible difference between compared cover samples), we fit a simple asymptotic growth curve, the natural growth function $[f(x)=a(1-e^{-bx})]$, to this data. Parameters (a,b) were estimated by least squares estimate using a non-linear regression algorithm (Marquardt 1963).

Effects of Burrowing

During the same period, the number of burrow mounds were counted within a 25 m x 25 m square (0.0625 ha) of which the sampling site was the center. We determined the relationship between the density (ha^{-1}) of burrow mounds (independent variable, random effect) and D (dependent variable) by regression. For calculations of r, significance ($P \leq 0.05$) was evaluated using the F-statistic (Cacoullos 1965).

RESULTS

Changes in Plant Composition

The off-colony site was dominated almost completely by buffalo grass, western wheatgrass, Japanese brome (Table 1), while sand dropseed and six-week fescue were minor community constituents (<5% cover). Other species present (<2.0% cover), though not among the 20 species use to calculate multi-species cover, were green needlegrass (*Stipa viridula* Trin.) and needle-and-thread (*S. comata* Trin. & Rupr.). On-colony sites near the edge had low forb:grass ratios (Fig. 1a) though most perennial mid-grasses, e.g. sand dropseed, green needlegrass and needle-and-thread were virtually absent (<0.5% cover). Forb: grass ratios were highest (1.73:1 in 1981, 1.62:1 in 1982, and 8.59:1 in 1983) in the core of the colony (from 0 to 50 m from the center). A taxonomically diverse array of annual forbs were dominant at the core, including prostrate vervain, buckhorn, cut leaf nightshade, rough pigweed (*Amaranthus retroflexus* L.), tumble- tumbleweed (*A. albus* L.), poverty weed and Russian thistle. Tumblegrass, a perennial graminoid that frequents disturbed soils, was also an important constituent of this community. Unexpectedly, forb: grass ratio increased from 0.08:1 (1981) to 1.21:1, two years later, in a small (<0.3 ha) mid-colony zone (MCZ) about 350 m from the colony center. This zone was completely surrounded by grass dominated communities. The dominant constituents of MCZ were prostrate vervain, horseweed, and red threeawn (a perennial grass).

TABLE 1. Canopy cover of plant species (>2.0% cover) in the off-colony site.

Species	Canopy cover (± SD) off-colony 1981 n=9	1982 n=9	1983 n=9
	---------- % --------		
Buffalo grass	80 (6)	79 (12)	86 (8)
Western wheatgrass	5 (4)	6 (2)	5 (3)
Sand dropseed	2 (2)	2 (<1)	2 (<1)
Six-week fescue	3 (1)	4 (1)	2 (2)
Japanese brome	5 (1)	4 (3)	9 (5)

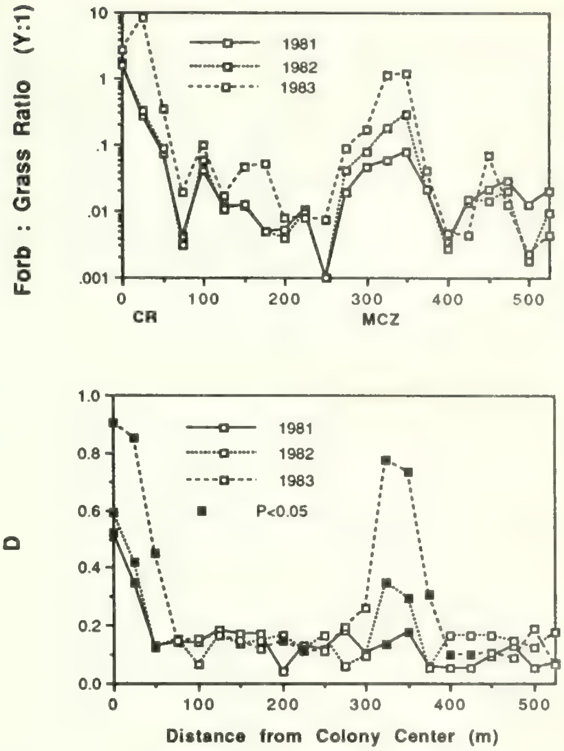

Figure 1.--Three year comparisons of: (a) the ratios of forb to grass cover along the colony profile; (b) the differences in multi-species (20 species) cover, D, between on-colony and off-colony sites along the profile. Locations of zones of extensive compositional change, the core (CR) and mid-colony zone (MCZ), are indicated.

During the study, D increased mainly in the core and surrounding MCZ (Fig. 1b). Also, D increased on sites adjacent to the original core, thus enlarging its radius by about 25 m in two years. Although there was a positive correlation between forb:grass ratio and D (r=0.72, F=6.14, 64 df, P<0.001), forb:grass ratio was not always a true indicator of change; some compositional changes involved the replacement of perennial grass species by other grasses (e.g., buffalo grass was sometimes replaced by red threeawn or tumblegrass).

Rate of Compositional Change

Upon plotting D[t+1] as a function of D[t], we noted a difference between points representing "highly disturbed" zones of the colony (the core and MCZ), and those from the remaining locations along the profile. Highly disturbed zones showed a high positive correlation between yearly states (r=0.84, F=11.5, 12 df, P<0.001). Application of the the natural growth function to these data (Fig. 2) yielded a good fit (R^2=0.72, P<0.001). The remaining points, where grasses dominated, were clumped near the origin. On these sites, yearly states were negatively correlated (r= 0.53, F=3.32, 28 df, P<0.01)

Effect of Burrowing

The density of burrow mounds and D (Fig. 3) were positively correlated (r=0.58; F=3.76, 64 df, P<0.01). However, linear, exponential, and polynomial regressions of these variables yielded poor fits (R^2<0.38). Burrow mounds, and disturbed soil directly adjacent to mounds were observed to be sites for initial establishment of annual forbs. In highly disturbed zones, annual forbs, dwarf shrubs (e.g., pasture sagebrush [Artemisia frigida Willd.]) and some "pioneer" perennial grasses (e.g., red threeawn and tumblegrass) occupied the ground surface between mounds.

Discussion

The differential extinction, replacement and resilience of plant species during prairie dog inhabitancy create the observed pattern of community change. Knowing the long-term response of similarly behaving plant species (Harper 1977; rather than taxonomic affinities) may help range and wildlife managers understand prairie dog induced succession. We considered species on the prairie dog colony to fall roughly into four categories: (1) perennials that quickly disappeared after initial prairie dog inhabitancy; primarily mid-grasses, e.g. sand dropseed, green needlegrass, and needle-and-thread; (2) shortgrasses that were initially resistant to the impacts of prairie dog grazing, e.g. buffalo grass (Fig. 4); (3) annuals that became established on recently disturbed soil associated with burrow mounds, e.g. buckhorn, prostrate vervain, and scarlet mallow; (4) annuals and perennials that only became established on the most disturbed sites, e.g. poverty weed. Although the

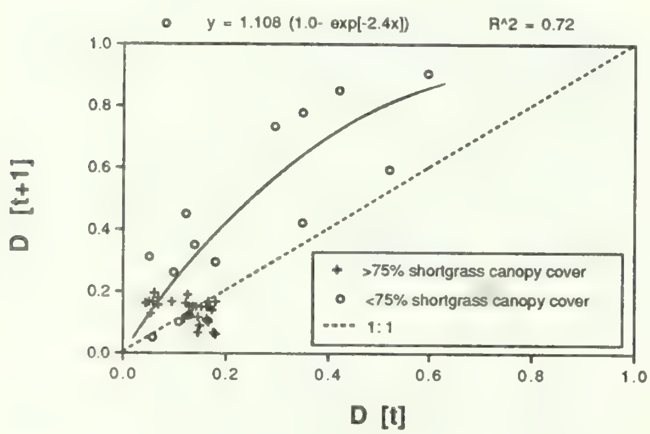

Figure 2.--Year to year changes in the difference between multi-species cover, D, between on-colony and off-colony sites. The natural growth function was fit to points (n=14) that went below 75% shortgrass canopy cover during the study. A year to year increase in D was not observed for points (n=30) above this threshold.

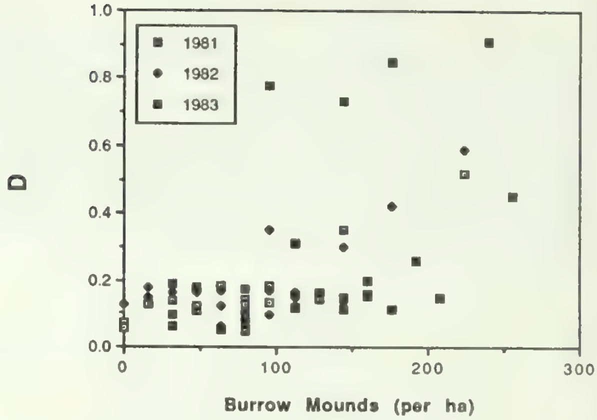

Figure 3.--The relationshp between the difference in multi-species cover between on-colony and off-colony sites, D, and the density of prairie dog burrow mounds.

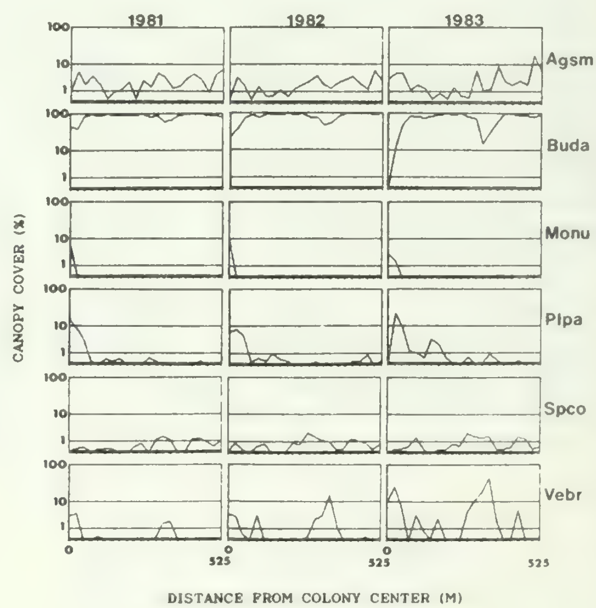

Figure 4. Mean canopy cover for six plant species along the colony profile for three consecutive years. The species are western wheatgrass (Agsm), buffalo grass (Buda), poverty weed (Monu), Patagonia Indianwheat (Plpa), scarlet mallow (Spco), and prostrate verfain (Vebr). The Y-axis is transformed using $Log_{10}(Y+1)$. Distance from the colony center to an edge 525 m distant was measured in 25 m intervals.

cover of western wheatgrass initially decreased with prairie dog inhabitancy, the species was not displaced entirely as were all other mid-grasses. The ability of this species to maintain a presence under intense prairie dog grazing may be due to the survival of decumbent "grazing" ecotypes that are known to occur in some prairie dog colonies (Detling and Painter 1983).

At the colony edge, plant composition was not radically affected by the loss of mid-grasses. Reduction of mid-grass cover, resulting from prairie dogs clipping tall plants for predator avoidance rather than for forage (King 1955), may have a greater consequence on more mesic grasslands (Archer et al. 1987). The initial 2 yr period of soil disturbance, resulting from building burrow mounds and allowing the introduction of some annual forbs, had a minor impact on the plant community. However, long-term inhabitancy of prairie dogs on mixed-grass prairie vegetation in our location (we estimate from 11 to 13 yrs) can cause the complete disappearance of perennial shortgrasses between mounds.

The nature of soil disturbance and plant community structure varied markedly between the two characteristic types of burrow mounds (King 1955, Sheets et al. 1971), (1) dome mounds and (2) crater mounds. Whereas these structures may reach 1 m in height and 2.5 m in diameter in an old colony (King 1955), all were less than half these dimensions in our colony. Dome mounds were composed of loosely packed subterranean soil spread widely over the ground surrounding the entrance. These mounds became sites for the establishment of a variety of forbs that assumed a prostrate habit, either as a consequence of their natural growth form (Warwick and Briggs 1980) or because they were heavily clipped by prairie dogs. Prostrate vervain, tumbling mustard, buffalo bur (Solanum rostratum Dunal), and cut leaf nightshade were frequent occupants of dome mound sites in our study colony.

"Crater mounds" were narrow, roughly cone-shaped structures that prairie dogs constructed from uprooted vegetation, displaced litter, humus, and mineral soil which they scraped from a patch adjacent to the burrow entrance. After a rain, prairie dogs packed the material tightly with their noses. Thus, surfaces of the crater mounds made poor sites for seedling establishment. However, adjacent "quarried" patches were invaded by annual forbs, most frequently buckhorn, during the following spring.

On our colony, the buffalo grass dominated community experienced a resilient period (probably from 4 to 7 yrs) during which little change occurred. This may be a period during which root carbohydrate reserves were being depleted (Santos and Trlica 1978), both to supply above ground regrowth and from increased microbial grazers below ground (Ingham and Detling 1984). A decisive shift in composition was experienced when shortgrass was replaced by a mixture of armed and/or sprawling grasses and forbs, aromatic dicots, and bare ground. The shortgrass "threshold" at our location was 75% cover; sites that went below this level experienced abrupt changes in composition during the following year. Thus, sites below threshold slipped from temporary stability into the asymptotic increase in D that we have described.

Although compositional changes in colonies are likely to be most evident in an expanding core, irregular patches closer to the periphery may undergo change, as well. Archer et al. (1987) concluded that the formation of forb dominated communities in prairie dog colonies could be attributed mostly to the length of time of sustained prairie dog activity. The initial amount of shortgrass cover may also affect the rate of prairie dog induced succession. Since prairie dog colonies are aggregates of highly territorial family groups (coteries) rather than a cooperating colonial entity (King 1955, Hoogland 1981), population and activity of prairie dogs is non-uniformly distributed across the colony. Whereas territories at the core are contiguous, those at the edge of expanding colonies are often spread spaciously amongst relatively undisturbed vegetation. Thus, compositional changes outside the core are likely to be patchy. In our study site, compositional changes outside the core area (in MCZ) appeared to result from sustained inhabitancy of a single coterie on a site with below average shortgrass cover.

In many colonies in the Badlands area, the presence of a shortgrass understory imparts resiliency to the plant community, delaying the eventual shift to annual forbs that is usually incompatible with range livestock management objectives. It should be noted, however, that prairie dog colonies provide valuable forage resources for native ruminants; pronghorns (Antilocapra americana) prefer the high quality herbage in colony cores (Krueger 1986), while bison are attracted to the highly nitrogenous, low fiber regrowth of grasses at the edges of colonies (Coppock et al. 1983). Extrapolation of results from this study to other prairie dog colonies should be done cautiously. In fact, where plant composition and herbivore use is much different from the single colony studied, extreme care should be used in extrapolating these results to other areas.

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Abstracts

CARNIVORES

Effect of Coyote Removal on Mule Deer Survival in Colorado. White, Gary C., Richard M. Bartmann and Len H. Carpenter.

The effect of coyote (Canis latrans) removals on the survival of mule deer (Odocoileus hemionus) fawns was evaluated in the Piceance Basin of northwest Colorado. Fawns were radio collared during November and survival monitored through the following June for the winter of 1981-82 through 1987-88. Coyotes were removed during the winters of 1985-86 through 1987-88. Overwinter fawn survival ranged from 3.5% (SE 2%) during the severe winter of 1983-84 up to 33% (SE 6%) in 1982-83. The proportion of fawns dying from predation decreased ($P = 0.001$), and the proportion of fawns dying from malnutrition increased ($P = 0.043$), but overwinter fawn survival did not increase ($P = 0.36$) during coyote removal.

Livestock Guard Dogs Protect Sheep from Coyote Predation in Colorado. Andelt, William F.

The effectiveness of livestock guard dogs for protecting domestic sheep (grazed in fenced pastures or on open range) from predators in Colorado was determined with two postal and two telephone surveys during 1986. A total of 174 of about 450 Colorado Wool Grower Association members responded to a general survey. Responses from 123 of the producers were used to estimate sheep losses for producers without guard dogs (respondents with guard dogs, individuals without sheep, and incomplete responses were eliminated). Responses from 21 of the non-respondents were obtained by telephone. Twenty-one of 30 producers suspected or known to use guard dogs with sheep responded to a second postal survey; the survey was completed by interviewing non-respondents by phone. Twenty-two responses were used to estimate sheep losses for producers using guard dogs with sheep (respondents without guard dogs or sheep, and incomplete responses were eliminated). Respondents and non-respondents to the postal survey that did not use guard dogs averaged 660 ewes and 846 lambs and 369 ewes and 460 lambs, respectively, whereas guard dog owners averaged 1217 ewes and 1518 lambs. Respondents and non-respondents without guard dogs reported an average of 1.1% and 1.1% of the ewes and 5.9% and 3.4% of the lambs lost to coyotes whereas producers using guard dogs reported 0.4% of the ewes and 0.9% of the lambs lost to coyotes during 1986.

URBAN

Controlling Raccoon Damage in Urban Areas. Riley, David G.

Raccons have become a serious problem in many urban and suburban areas. Damage to homes and buildings as well as the spread of diseases to pets are constant problems when high raccoon populations occur. Various control methods can be implemented with positive results.

An Evaluation of Hazing Methods for Urban Canada Geese. Aguilera, Elizabeth, Richard L. Knight, and John L. Cummings.

The efficacy and latency period of two hazing methods of Canada geese (Branta canadensis) were tested in Fort Collins, Colorado urban areas between November 1988 and January 1989. The hazing methods evaluated were screamer shells and alarm calls. Five replications of each method were addressed for a total of 10 experimental field trials. Each trial consisted of three periods: pre-treatment, treatment, and post-treatment. The first two periods lasted five days and the third depended on the time it took Canada geese to return to the area. Each method was applied for ten minutes two times a day until the geese left the area. The screamer shell was significant in reducing the number of geese at an area up to ten days after the treatment was stopped, however, the alarm call was not effective in hazing geese from an area.

Effects of Animal Welfare Philosophy on Wildlife Damage Control. Schmidt, Robert H.

Wildlife damage prevention and control activities are often criticized when they involve the deaths of wild animals. However, just as the nuclear industry has failed to convince the majority of the public that its industry is safe, education will fail to convince the public that all wildlife damage control techniques are humane. Animal welfare-related legislation,

university rules on the use of wild animals for research, and litigation are changing the working environment of our profession. This paper reviews aspects of the animal welfare movement as they affect the wildlife damage prevention and control profession and discusses future strategies for living with it.

BIG GAME

Characteristics of Deer Damage to Experimental Orchards in Ohio. Mower, Kerry J., Thomas W. Townsend, and William J. Tyznik.

We measured newly established apple trees (1) to compare growth differences between trees damaged by browsing deer (Odocoileus virginianus) and trees protected from deer, (2) to determine seasonal patterns of browsing, and (3) to determine if deer browsed selectively among Ohio's 3 most commonly planted apple cultivars. Experimental trees were measured from June 1986 through May 1988.

Experimental orchards were planted at research farms representative of areas where apples are grown commercially. All experimental orchards contained 20 trees each of red delicious, golden delicious, and red rome. Trees were planted randomly by cultivar pairs and one tree of each pair was enclosed in a welded wire cylinder 1.5 m high to exclude deer. Eight orchards were planted the first year; 5 additional orchards were planted the second year. At the beginning of the second year half of the tree pairs in the 8 original orchards were randomly selected and the exclosures switched from control to treatment trees. Trees were measured monthly the first year but bimonthly the second year because the trees had become much larger. Variables measured included branch length, number of leaves/branch, number of leaves/cm of branch length, and browsing frequency. Radial growth was determined by measuring trunk diameter at time of planting and each autumn thereafter.

Length of branches in all orchards but 3 were significantly reduced by browsing deer and browsed trees in all but 2 orchards had significantly reduced numbers of leaves ($p < 0.05$). Browsed branches were observed in all but 1 orchard. The reduction in branch length ranged from 0% in the single undamaged orchard to 98% in one of the most severely browsed orchards; reduction in number of leaves/branch ranged from 0% to 85%.

Significant seasonal effects were found in branch length, number of leaves/branch, and browsing frequency between browsed and control trees ($p < 0.05$). Two seasonal patterns existed among significantly browsed orchards. Browsing was concentrated either in early summer or autumn. Orchards with greatest branch and leaf reductions sustained significantly more browsing in early summer than any other season. Browsing in severely damaged orchards began as soon as trees began to grow and decreased only when trees failed to initiate new growth, became dormant, or died. Orchards with lower levels of browsing were damaged in late autumn and winter. Browsing began in the less severely damaged orchards at the time leaves dropped from trees in adjacent wooded areas. Leaves persisted on apple trees longer than in surrounding forest trees. Sporadic browsing continued into winter in such orchards.

No evidence was found that deer selectively feed on any of 3 cultivars tested. Browsing was severe enough to cause higher mortality among treated trees in 6 orchards ($p < 0.01$). Four orchards were moderately browsed; mortality rates between browsed and unbrowsed trees were not different but radial growth was reduced significantly among browsed trees. Three orchards were browsed lightly, but neither mortality rate nor radial growth was significantly different between browsed and unbrowsed trees.

After 2 growing seasons, most foliage was beyond the reach of deer. Browsing damage was most critical to small and immature trees. Under conditions of rapid growth, apple trees may reach a size beyond which deer browsing does not impact growth significantly. At some sites, protection might be needed only the first 2-3 years.

Impacts of Pronghorn Grazing on Winter Wheat. Torbit, Stephen C., R. Bruce Gill, James F. Liewer, and A. William Alldredge.

In 1983 a 3-year project was initiated to evaluate the impacts of pronghorn grazing on winter wheat in eastern Colorado. To fully assess the potential impacts of pronghorn grazing, the study was designed to achieve the following objectives:

1) Determine seasonal habitat use by pronghorn in areas containing both winter wheat fields and native grasslands;

2) Determine the relationship between winter wheat use by pronghorn and nutritional characteristics of winter wheat and native forage diets;

3) Measure the response of grain yield to foraging by free-ranging pronghorn;

4) Measure the response of grain yield to controlled foraging experiments with hand-reared pronghorn confined exclusively to wheat fields.

Systematic aerial surveys and reobservation of banded and telemetered pronghorn revealed a seasonal shift to wheat fields in November of each year, however, all pronghorn abandoned wheat fields by early May. Peak use of green wheat fields occurred from November through April. By radio-tracking pronghorn we also observed daily movements between wheat fields and native prairies. Native diet quality, as measured by percent cell contents and crude protein content, declined from October through February and increased after February. Forage quality of

winter wheat increased from October through February and declined thereafter. By May, native forages were nutritionally superior to winter wheat. Free-ranging pronghorn were excluded from grazing on a winter wheat field by a paired plot experiment. The impact of grazing by these pronghorn on final grain yield was not measurable. Hand-reared pronghorn were allowed to graze in fenced wheat pastures from November through May in a controlled experiment. Captive pronghorn removed measurable amounts of green biomass but this removal did not significantly (P = 0.19) reduce final grain yield. Grain yields were not affected despite a stocking rate approximately 80 times that observed with wild pronghorn. The alternating quality of native forage and winter wheat appear to induce a rotational grazing pattern with pronghorn. Wheat is exploited during its early growth when it is nutritionally superior to native forages. Wheat is also most resistant to grazing at this stage. By the time wheat reaches the elongation state when it is most susceptible to damage by grazing, native forages have eclipsed the nutritional quality of winter wheat and pronghorn shift their grazing from wheat to native grasslands. Our results demonstrate that pronghorn grazing on winter wheat is inconsequential when compared to other environmental factors (soil types, precipitation, etc.). It is apparent that winter wheat and pronghorn should be considered complementary resources in mixed rangeland-cropland habitats.

Analytical Chemistry in the Animal Damage Control Program. Mishalanie, Elizabeth A., and Edward W. Schafer, Jr.

Analytical methods related to current and potential Animal Damage Control (ADC) chemicals need to be developed and frequently updated to provide the necessary support for the research and registration-related activities of the ADC Program. Registration-related activities require the development of analytical methods to support the following: field efficacy trials; residue trials; laboratory feeding trials; quality control tests for baits and formulations; stability and longevity studies; soil, water, and vegetation accumulation and metabolism; animal metabolism; and the development of human health/application use restrictions. Other registration-related activities may involve one-time chemical studies such a hydrolysis and photodegradation studies. Analytical methods are also needed to assist in the search for new chemicals for use in vertebrate pest control, for the identification of safe and reliable physiological and mechanical markers used in tracking and migratory studies, and in the assessment of the efficacy and selectivity of baiting techniques.

BIRDS

Anthranilates as Bird Repellent Feed Additives for Reducing Feedlog Damage: An Overview. Glahn, James F.

Anthranilate derivatives, namely dimethy anthranilate (DMA) and methyl anthranilate (MA), which are human food flavorings, have a long history of study as potential bird repellents. Recent studies, initiated in 1984, investigating the potential use of these flavorings as bird repellent feed additives are summarized. These studies have included a number of laboratory, large pen, simulated field, and actual field studies at various concentrations of DMA and MA to evaluate their effectiveness in reducing feed loss damage by blackbirds and starlings. Companion studies on acceptance and performance of livestock with up to 1.0% DMA and MA in their rations are also summarized. Based on these studies and an economic assessment it appears that low concentrations of methyl anthranilate could be cost-effectively used to protect livestock feed with minimal effects on livestock.

RODENTS & LAGOMORPHS

Mound Building Rates of Plains Pocker Gophers Geomys bursarius, introduced on alfalfa fields. Luchsinger, James C., and Ronald M. Case.

Pocket gophers reduce forage yields by consuming vegetation and by the adverse effects of their tunneling and mound building (reducing plant vigor, smothering plants, and changing species composition). We are investigating the response of two different alfalfa varieties to the presence of pocket gophers in order to assess the possibility of using cultural methods to lessen the impact of pocket gophers on alfalfa yields.

Four paired plots were established for each alfalfa variety, a tap-rooted variety (Wrangler) and a fibrous-rooted variety (Spredor II). Each pair consisted of a control (no gophers) and experimental (gophers present) plot. Pocket gophers were stocked at a density of 6/hectare. Tunnel construction as indicated by the presence of surface mounds pushed up by pocket gophers, was checked at 3 to 13 day intervals. Our objective was to determine whether there was a difference in tunnel construction by pocket gophers in either of the alfalfa varieties.

We gathered data on 8 plains pocket gophers over at least 50 days. Mound production per pocket gopher ranged from 59 (over 57 days) to 154 (over 85 days). Mean mound production for the eight gophers was 100. The four gophers on Wrangler produced an average 1.2 mounds/day. The four gophers on Spredor II produced an average 1.6 mounds/day. We were unable to detect any significant differences in the rate of mound building among sex, age, or body size.

Efficacy of Three Formulations of Zinc Phosphide for Black-tailed Prairie Dog Control. Hygnstrom, Scott E., and Peter M. McDonald.

Studies have compared the efficacy of zinc phosphide to other toxicants, in particular strychnine and sodium monofluoroacetate, for controlling prairie dogs (Cynomys spp.). In most states, however, zinc phosphide is the only toxicant that is currently registered by the EPA for controlling black-tailed prairie dogs (C. ludovicianus). Various formulations of zinc phosphide are marketed but their relative efficacy is unknown. Prices and availability also vary. We compared the efficacy and cost of 3, 2.0% zinc phosphide baits for controlling black-tailed prairie dogs [2.0% zinc phosphide-treated steam rolled oats (ZP-rolled oats), Pocatello Supply Depot, U. S. Fish and Wildlife Service, Pocatello, Ida.; ZP Rodent Bait-AG crimped oats (ZP-crimped oats), Bell Laboratories, Inc., Madison, Wis.; and ZP Rodent Bait-AG pellets (ZP-pellets), Bell Laboratories, Inc., Madison, Wis.]. We conducted this study on 13 black-tailed prairie dog colonies in central Nebraska during November-December, 1988. We continuously searched the colonies (all were < 8 ha) during the study for evidence of black-footed ferrets (Mustela nigripes) but none was found. We established 66, 0.4-ha areas within these colonies to serve as treatment plots. A 0.4-ha control plot was established within 100 m of each treatment plot. We prebaited treatment plots with untreated stream-rolled oats according to zinc phosphide pesticide label recommendations. After 2-3 days, we randomly assigned and applied each zinc phosphide formulation, according to label recommendations, to 22 separate treatment plots. We used a plugged burrow technique to estimate the activity of prairie dogs 3 days after treatment. The differences in activity between the treatment and associated control plots were used to determine the relative efficacy of the 3 formulations. Active prairie dog burrows were reduced 80% with ZP-rolled oats, 78% with ZP-crimped oats, and 71% with ZP-pellets. A one-factor ANOVA revealed that there were no significant differences ($P = 0.322$) in efficacy among the 3 treatments. Data were independent, normally distributed, and variances among treatments were homogeneous. Material costs varied among treatments (ZP-rolled oats-$1.04/kg, ZP-crimped oats-$1.32/kg, and ZP-pellets-$2.21/kg). The costs of labor (@ $5.00/hr) for applying the prebait and bait were $18.07/ha for each treatment. The total costs per ha for 70-80% control of black-tailed prairie dogs were $18.71 for ZP-rolled oats, $18.82 for ZP-crimped oats, and $19.16 for ZP-pellets.

Responses of a Black-tailed Prairie Dog Population to Experimental Exploitation. Cox, Mike K., and William L. Franklin.

Survival, natality, movement, and body condition were examined in an exploited black-tailed prairie dog population in western Nebraska. Both colonies in the population were exploited at an average rate of 0.44 for two consecutive years. The nonremoval survival rate for the old colony decreased from 0.68 after the first removal, to 0.25 after the second removal. The new colony's nonremoval survival severely declined from 0.63 to 0.18, due in part to badger predation. The overall pregnancy rate of yearlings and adults in the population was 0.92, and the mean litter size ranged from 3.06 to 5.38 pup/lactating female. Because of the possible compensatory mortality in the winter months, disappearance in the summer months had the greatest impact on nonremoval survival.

Monofilament Lines Repel House Sparrows. Aguero, Danilo A., Ron J. Johnson, Kent M. Eskridge, James E. Knight, and Donald H. Steinegger.

Observations in New Mexico indicated that clear 8-pound-test monofilament line spaced at 30.5 cm (1 foot) intervals excluded house sparrows (Passer domesticus) from strawberries and stopped bird (species undetermined) damage to grapes. In other uses, it protected sprouting plants and peach trees from house sparrow and other bird damage, and effectively stopped barn swallow (Hirundo rustica) nest-building under eaves of a house. Five follow-up experiments with controls were conducted at the University of Nebraska. In experiment 1, lines spaced 30.5 cm apart around grape plants did not reduce American robin (Turdus migratorius) and European starling (Sturnus vulgaris) entries into the plants nor damage to grapes. Experiments 2 through 5 used baited stations to evaluate size (4-, 12-, and 20-pound-test weight), orientation (north-south, east-west, horizontal, vertical), color (clear and flores-cent yellow-orange), and spacing (30.5 and 61 cm) of monofilament line. Results of food consumption and bird count data indicate that all treatments repelled house sparrows. Blue jays (Cyanocitta cristata) and northern cardinals (Cardinalis cardinalis) were repelled somewhat but numbers of observations were small. Eleven other species at baited stations appeared not to be repelled by the lines. Although current experiments to refine management applications and to understand the underlying mechanism are not completed, we conclude that monofilament lines may effectively reduce house sparrow problems at some sites.

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-172

Recent Historical and Projected Regional Trends of White-Tailed Deer and Wild Turkey in the Southern United States

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David E. Chalk
Noel D. Cost
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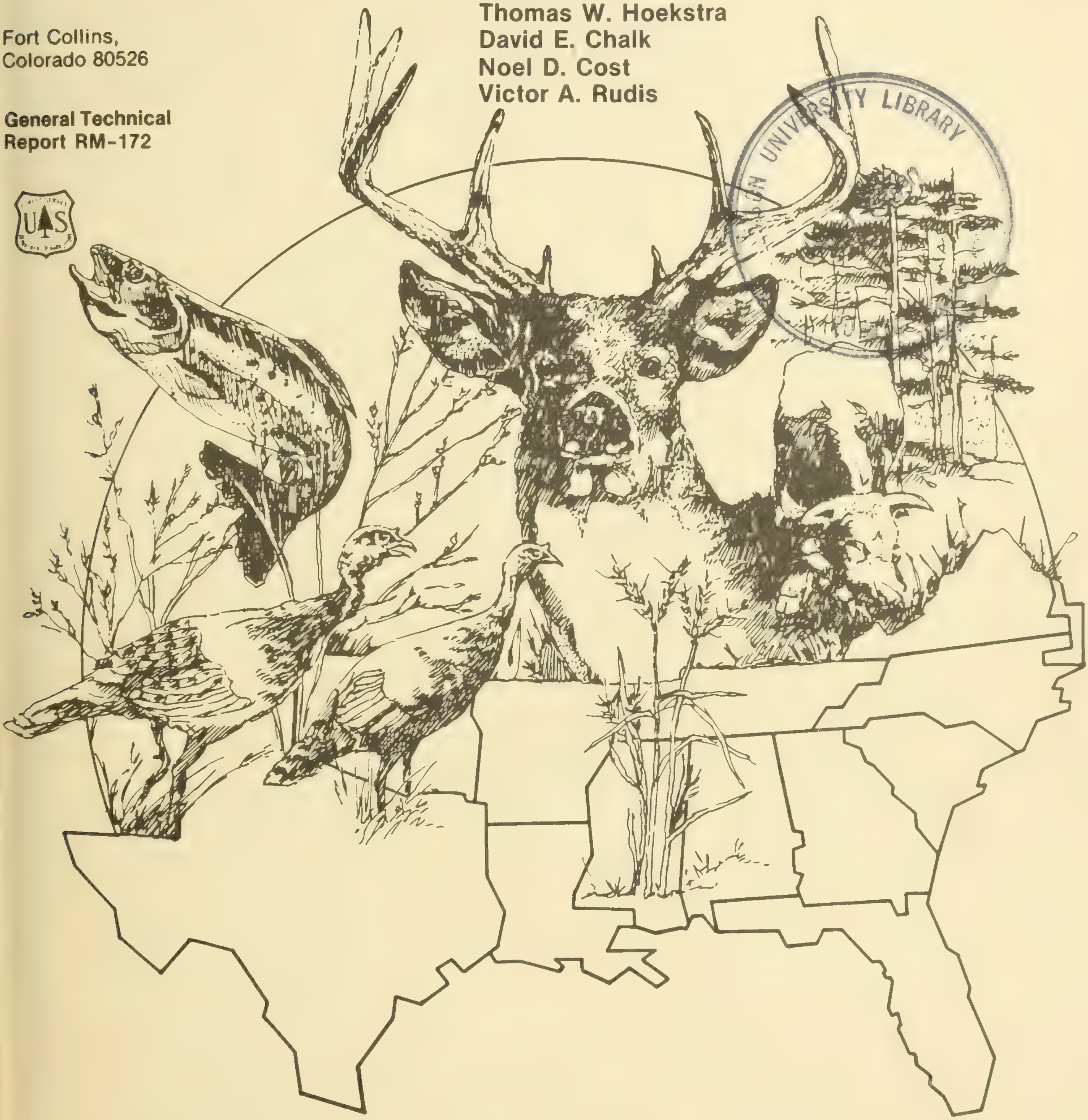

Abstract

Large-scale resource assessments are required by the Forest and Rangeland Renewable Resources Planning Act of 1974. This report describes the wildlife component of a regional modeling framework used to analyze multiple resource response to land management. The modeling framework, as applied in the southern United States, links fish, forage, water, and wildlife resources to land use and timber models. White-tailed deer and wild turkey were selected for analysis and their recent historical status was reviewed. Habitat-based wildlife models were developed to analyze the impacts of land use and timber management. Discriminant function analysis was used to model the relationship between deer and turkey density classes with areal estimates of cropland, rangeland, urbanland, timber management types, and forest age classes within a county. Projected changes in the land base for a baseline and several alternative scenarios were applied to the wildlife models. Over a 50-year projection period, deer and turkey densities declined in response to increasing urbanization and conversion of natural forest types to pine plantations. This research has improved the capability to assess wildlife over large geographic areas and has demonstrated the feasibility of developing regional multiple resource analysis systems from existing land base inventories.

Acknowledgments

The authors acknowledge the assistance of Joe McClure and Roy Beltz, project leaders for the Southeastern and Southern Forest Inventory and Analysis Projects, in providing forest inventory data. State wildlife agency personnel were invaluable in providing statistics on populations, harvest, and use. James Dickson, Michael Lennartz, and James Wentworth provided constructive reviews of this research while in progress.

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Recent Historical and Projected Regional Trends of White-Tailed Deer and Wild Turkey in the Southern United States

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Recent Historical and Projected Regional Trends of White-Tailed Deer and Wild Turkey in the Southern United States

Curtis. H. Flather, Thomas W. Hoekstra, David E. Chalk,
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INTRODUCTION

Large-scale, multiresource analyses and planning are mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA).[2] This law requires the Forest Service to produce national descriptions of the current status and projections of future supply and demand for all renewable natural resources, including wildlife and fish.

Although identifying broad information needs, the law does not specify how national-level evaluations of natural resources are to be accomplished. Hoekstra and Hof (1985) identified three technical components that a national wildlife and fish assessment should address, including: (1) the recent historical trends in resource inventories (supply) and use (demand), (2) projections of resource inventories and uses, and (3) evaluations of opportunities to improve the future wildlife and fish resource situation. Components 2 and 3 require methodologies to project resource supplies and demands. In general, past wildlife and fish assessments (USDA Forest Service 1977, 1981) have only partially accomplished these tasks and, in many cases, have relied on resource specialists to speculate on future resource trends and management opportunities. Apart from a limited technical capability, past assessments also were criticized for not analyzing resources in the context of a multiple resource system; that is, the impacts or trade-offs of one resource on another were not addressed (Schweitzer et al. 1981). For wildlife resources, such evaluations require the capability to predict resource response to general land management activities.

A fundamental requirement of multiresource planning is to describe and monitor impacts of resource management on all resources, including wildlife. Modeling wildlife response to land management activities, however, is difficult (Hench et al. 1985). Techniques comparable with those being used for timber resources are generally not available (Crawford 1984). Consequently, there is a need to develop methods that will permit wildlife planning specialists to prescribe resource management based on impacts from likely future management alternatives.

One of the most insistent problems in meeting the legislative requirements implied by the RPA is developing objective, quantitative methodologies that are appropriate for national-level evaluations of wildlife and fish. Although there have been recent efforts to develop objective models that relate wildlife species to habitat quality, the focus of these models has been to predict resource development impacts on wildlife habitat at a site-specific level (Hawkes et al. 1983). There is a need to recognize that informed resource planning decisions cannot be made exclusively at the site level (Risser et al. 1984). More emphasis is needed on analyses that explicitly address large geographic areas (Gall and Christian 1984, Sanderson et al. 1979).

This paper describes the wildlife component of a regional multiresource modeling framework that was developed to analyze multiple resource response to land management activities. The method discussed here improves the analytical basis for national wildlife assessments by developing regional supply projection models in a multiple resource context. The region (multiple states) was chosen as the geographic unit for analysis because environmental and economic attributes are more homogeneous within a region than at the national level (Joyce et al. 1986). The southern United States was the focus of a regional evaluation of the timber resource (USDA Forest Service 1988) and, therefore, served as an appropriate pilot test area for the regional multiple resource modeling framework proposed for national assessments of natural resources.

The objective of the wildlife modeling effort was to develop regional abundance models that were consistent and responsive to models that predicted regional shifts in land use (Alig 1984) and timber inventory characteristics (Tedder et al. 1987). This paper reports on the models developed for white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*). Before discussing the wildlife modeling approach and application, we review the recent historical situation of wildlife resources in the South to provide a context within which to interpret the predicted future trends.

CURRENT STATUS AND RECENT HISTORICAL TRENDS

Current Resource Situation

The southern United States, from Texas to Virginia, supports one of the most diverse fauna in the country (table 1). The Southeast (Virginia, North Carolina, South Carolina, Georgia, Florida) and the South-central (Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Kentucky,

[2] *Public Law 93-378. United States Statutes at Large. Volume 88, p. 476 (P.L. No. 93-378, 88 Stat. 476).*

Table 1.—Comparison of the number of resident and common migrant vertebrate species (and subspecies of special concern) in the United States. Figures in parentheses represent percent of national total. Percentages across regions will not sum to 100% since species can occur in more than one region.

	NE	NC	SE	SC	GP	RM	PC	AK
Amphibians	49(25)	57(29)	85(43)	102(57)	32(16)	34(17)	52(26)	6(3)
Birds	344(38)	328(36)	357(40)	488(54)	373(41)	458(51)	389(43)	217(24)
Fish	208(20)	262(25)	505(47)	382(36)	167(16)	199(19)	236(22)	53(5)
Mammals	81(20)	107(26)	99(24)	172(92)	107(26)	200(49)	218(53)	71(17)
Reptiles	48(14)	75(22)	105(30)	145(42)	71(20)	115(33)	76(22)	1(*)
Total	730(25)	829(28)	1,151(39)	1,289(44)	750(26)	1,006(34)	971(33)	353(12)

NE - Northeast, NC - North-central, SE - Southeast, SC - South-central, GP - Great Plains, RM - Rocky Mountains, PC - Pacific Coat, AK - Alaska.

**Less than 1%.*

Source: USDA Forest Service (1981).

Table 2.—Participation in wildlife-associated recreation by persons 16 years old and older for the nation and the South.

	Nation		South	
	Number (thousands)	Percent of U.S. population	Number (thousands)	Percent of regional population
Hunting	17,444	10.3	6,751	12.0
Big game	11,806	6.9	4,393	7.8
Small game	12,362	7.3	4,970	8.8
Migratory bird	5,311	3.1	2,505	4.4
Other	2,642	1.6	1,040	1.8
Nonconsumptive	93,249	54.9	25,780	45.7

Source: USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

Tennessee, Alabama) regions are ranked 1 and 2 out of 8 national regions measured in terms of the absolute number of vertebrate species.

The diverse fauna of the South attracts a large number and variety of recreational users. Nonconsumptive users numbered over 25 million, while hunting opportunities in the region drew 6.7 million users in 1980. Of these hunters, 65% hunted big game, 74% hunted small game, and 37% hunted migratory birds (table 2). Relative to the nation, the South supported higher participation rates in hunting [12.0 ($\pm$0.2)% of the regional population compared to 10.3 ($\pm$0.1)% nationwide][3] while nonconsumptive participation [45.7 ($\pm$1.0)% of the regional population][3] was nearly 10 percentage points below the national rate.

The two most important game species in the South are the white-tailed deer and wild turkey (USDA Forest Service 1981). These species have been monitored and managed more intensively than most species in the region because of their importance to hunting. Consequently, the information base on deer and turkey populations, harvest, and use supported a detailed examination from both historical and future perspectives.

[3]*Estimates of standard errors were calculated from formulas and tables presented in appendix C of USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).*

Currently, the South supports approximately 8.6 million deer and 1.4 million turkeys.[4] White-tailed deer are widely distributed across the South and inhabit a variety of habitats (Halls 1984). Populations reach their highest densities in the coastal plain region[5] where blocks of dense cover within forested areas of limited tree canopy cover are considered optimal deer habitat (Short 1986).

Wild turkey is a less widely distributed species than white-tailed deer. In the South, turkeys appear to prefer woodlands that are open and mature, comprised of mast-producing species, with scant ground cover and good eye-level visibility (Eichholz and Marchinton 1976, Lindzey 1967). The interspersion of forests with grassy open areas for brood rearing and nesting is also an important component in turkey habitat. Speake et al. (1975) recommended that spring/summer habitat in the Southeast should be 12–25% forest openings. The highest population densities are found in the bottomlands of the Mississippi, but densities are also high in the coastal plain of

[4]*Unless otherwise cited, reported statistics on the population, harvest, and use of deer and turkey were obtained from state wildlife agencies.*

[5]*Southeastern Cooperative Wildlife Disease Study; turkey distribution map produced through Federal Aid in Wildlife Restoration Act, Contract No. 14-16-008-2024; deer distribution map produced through Cooperative Agreement No. 12-16-5-2230.*

Alabama, the piedmont region of Georgia and South Carolina, and the mountains of Virginia.[5]

In 1983, the South's game species populations supported approximately 2.8 million deer hunters and 570,000 turkey hunters, who harvested 1.4 million deer and 195,000 turkeys. Of those hunters that pursued big game in the South, 95% hunted white-tailed deer or wild turkey (USDI Fish and Wildlife Service and USDC Bureau of Census 1982). These recreationists spent over $11 million on hunting equipment, licenses, travel, and other related hunting expenditures (USDI Fish and Wildlife Service and USDC Bureau of Census 1982). State agencies depend on these expenditures (with the associated matching funds from federal programs) to manage their wildlife resources. Similarly, certain local economies depend on hunting-related expenditures, and the regional economy could be severely impacted if participation rates decline (Alward et al. 1984).

Although most big game are hunted on private lands, hunting on federal land is disproportionately high relative to the amount available. Federally administered lands comprise only 6% of the South's land base (USDA Forest Service 1981), yet 18.6% of the big game hunters used these public lands in pursuit of game (USDI Fish and Wildlife Service and USDC Bureau of Census 1982). The disproportionate use of federal lands cannot be completely accounted for by higher wildlife populations on these lands. National forests in 1980 supported 3.5% of the deer and 8.2% of the turkey populations in the South (USDA Forest Service 1982). Given that national forests comprise approximately 4% of the land base, the number of deer was slightly below, while turkeys were twice what was expected, assuming a distribution proportional to land area available. This illustrates the importance of public lands—particularly national forests which comprise 65% of the federal land in the South—in providing wildlife recreational opportunities in this region.

These estimates of population, harvest, and users present the status of the big game resource in the South for a single point in time. The magnitude of these numbers is difficult to interpret in terms of resource status without a historical review.

Historical Resource Situation

Following European settlement of the North American continent, deer and turkey populations declined dramatically from exploitation caused by market and subsistence hunting, and habitat destruction caused by industrialization, timber harvesting, and conversion of forested lands to agricultural uses (Aldrich 1967, Halls 1978, McCabe and McCabe 1984, Miller and Holbrook 1983, Mosby and Handley 1943). Population levels of wild turkey had declined to such low levels that Fay (1884) predicted imminent extinction. By the turn of the century, an estimated 300,000 white-tailed deer (McCabe and McCabe 1984) and 30,000 wild turkey (Miller and Holbrook 1983) remained in the United States.

The recovery of whitetails and turkey, beginning around 1930, is frequently cited as one of the most

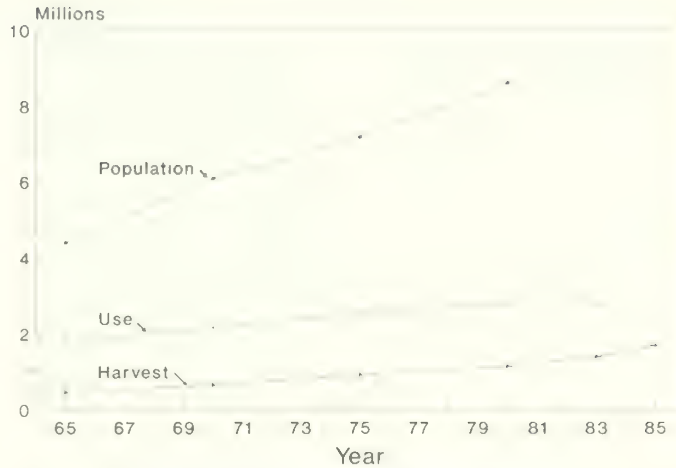

Figure 1.—Recent historical trends in deer population, harvest, and number of users for the southern United States.

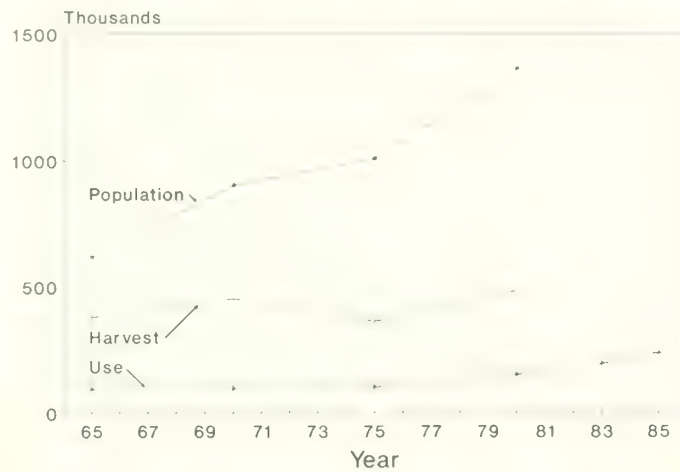

Figure 2.—Recent historical trends in turkey populations, harvest, and number of users for the southern United States.

significant accomplishments of modern wildlife management. The recovery was initiated by enforced protection, restocking programs, and habitat management. However, fortuitous land use changes greatly facilitated the observed increases in population. Regeneration of extensively clearcut forests, secondary succession on abandoned agricultural land, and migration of rural human populations to urban centers contributed greatly to the amount of suitable habitat available to the expanding populations (Barber 1984, McCabe and McCabe 1984, Miller and Holbrook 1983).

In more recent times, deer and turkey populations have continued to increase. Between 1965 and 1980, deer populations increased 96% from 4.4 to 8.6 million animals, for an average annual increase of approximately 282,000 deer (fig. 1). Harvest levels and number of deer hunters have increased as well, but at a slower rate. Over the same period, harvest levels increased 45,000 per year, while the number of hunters increased at an average annual rate of 70,000 (fig. 1).

Trends in wild turkey are qualitatively similar to deer trends (fig. 2). Turkey populations increased by 120% from 1965 to 1980, for an average annual rate of 50,000 birds. Harvests levels have increased 4,000 per year and

the number of turkey hunters increased 7,000 per year over the same period.

Deer and turkey population trends on national forests in the South do not show the significant gains reported across all ownerships (fig. 3). Deer populations remained fairly stable around 280,000 animals from 1965 through 1984. Conversely, turkey populations have increased steadily since 1965. Introduction of birds into previously unoccupied habitat has resulted in an average annual increase of approximately 4,000 birds. Although deer populations have remained stable, harvest of deer from national forests has more than doubled from 20,000 to 49,000 animals. Similarly, turkey harvest increased from 2,300 birds in 1965 to 10,400 birds in 1984.

Although the recent trends in deer and turkey populations, harvest, and users suggest a secure future for these resources in the South, there is evidence to suggest that increased expenditures for management will be required to maintain deer and turkey populations, and the quality of big game hunting (Bailey 1980, Halls 1984, Miller and Holbrook 1983). Increasing human populations mean increased demands for multiple products and uses from a finite land base. Consequently, there is a high potential for increased resource conflicts that will necessitate careful planning to ensure that multiple resource demands can continue to be supported across the region. To address multiple resource planning for wildlife resources, a modeling framework was developed to permit an assessment of wildlife response to land use and timber management changes. This framework represents the first time that wildlife models have been linked to changes in land use and timber management at a regional scale.

MODELING APPROACH

Wildlife habitat can be defined as the availability and interspersion of food, cover, and water. Habitat represents a spatial concept characterized by a particular combination of physical and biotic factors within a defined geographic area that determines whether an animal can survive and reproduce (Partridge 1978). The description of a species habitat is dependent on the scale of the resource management problem (Flather and Hoekstra 1985). At the regional scale, patterns in land use and forestland characteristics (e.g., forest type and age class) define a coarse representation of wildlife habitat appropriate for this level of analysis (Joyce et al. 1986, Klopatek and Kitchings 1985). Like wildlife habitat, other resources such as forage, fish, and water are also affected by the particular pattern of land use and land cover. It is this dependence on land base characteristics, made explicit through common definitions of land use and land cover types, that served as the basis for developing the multiple resource analysis framework, of which wildlife is one component.

The Multiresource Framework

A major obstacle in the development of multiple resource analyses has been the definition of a conceptual basis for linking resources. Joyce et al. (1986) proposed an analysis framework for integrating regional resource models for use in large-scale assessments of natural resources. The framework (fig. 4) links forage, wildlife, fish, and water resource models to three models that project changes in the land base.

Acreage projections in various land uses including cropland, pasture and rangeland, human land uses (urban, roads, farm structures, etc.), and timber management types (natural pine, planted pine, oak-pine, upland hardwood, lowland hardwood) were provided for each state by the Southeastern Area Model (SAM) (Alig 1984). Stand characteristics within each timber type were further described by the Timber Resource Inventory Model

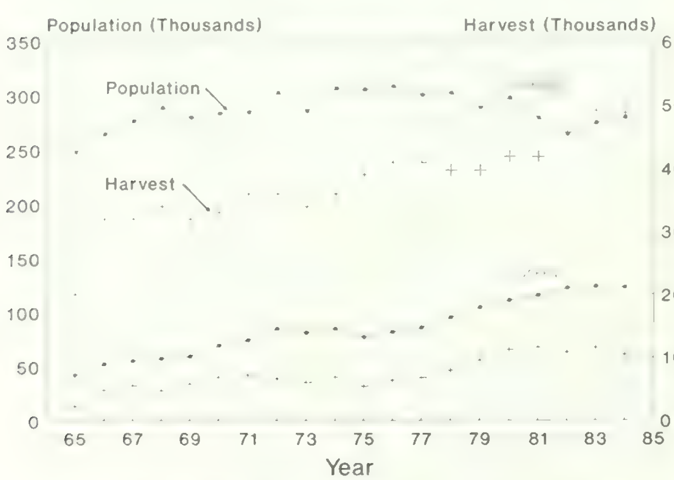

Figure 3.—Recent historical population and harvest trends for deer and turkey on National Forest System lands in the South (source: USDA Forest Service 1965-1977, 1978-1984).

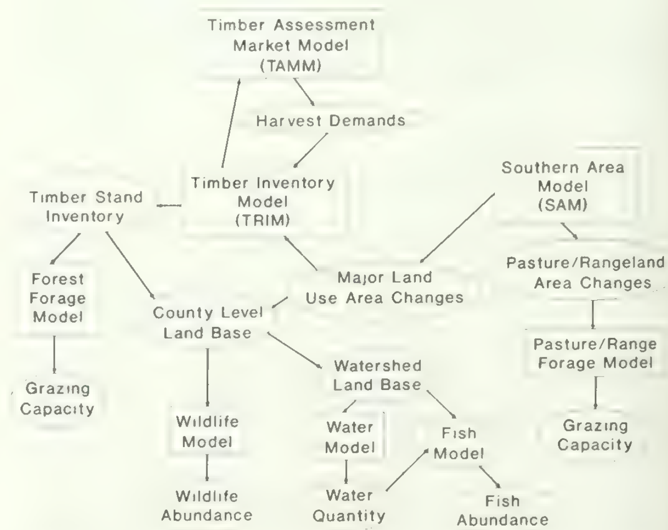

Figure 4.—Multiple resource model framework for linking individual resource models at the regional level. Boxes are models and ellipses are databases or model outputs. Arrows represent information transfers among resource models. (after Joyce et al. 1986).

(TRIM) (Tedder 1983, Tedder et al. 1987). The timber inventory model interacts with the Timber Assessment Market Model (TAMM) (Adams and Haynes 1980) to equilibrate supply (TRIM) and demand (TAMM) of forest products. The output from this equilibrating process is a subregional (Southeast and South-central) projection of the growing stock volume and land area estimates by ownership, timber type, site class, and age class categories.

To link the wildlife and other resource models to the land base projection, all models were required to operate from a commonly defined set of land use and forest cover descriptors. Linkage through a common land base classification was less constraining than requiring all resources to operate at a common geographic unit. Use of a commonly defined land base permitted the choice of the geographic unit deemed appropriate for each resource. An important geographic consideration in the wildlife analysis was species motility. Motility can either be modeled explicitly through the specification of dispersal functions or by analyzing geographic areas of sufficient size that motility is not a significant process. The latter approach was used to relate wildlife populations to spatially stationary habitat characteristics. The county was chosen as the geographic unit to establish the relationships between land use pattern and wildlife densities.

Currently, the potential influence of forage, wildlife, fish, and water resources on timber management and the economics behind land use changes and land management decisions has not been incorporated into the multiresource framework. The analysis system, at this stage of development, has been designed only to evaluate the impacts of land use shifts and timber management on other resources.

Wildlife Habitat Models

Prediction models for wildlife can be categorized into two broad classes: population parameter models and habitat-based models. Prediction of wildlife populations based on estimates of population structure, natality, and mortality rates is difficult, and few techniques are applicable to regional and national analyses (Hawkes et al. 1983). In addition, wildlife impacts cannot be evaluated unless the functional relationships between population parameters and land management actions are known.

An alternative means of modeling wildlife resources is through habitat-based approaches. The occurrence and abundance of wildlife species are generally recognized to be influenced by the relationship of a species to its habitat. Although the influence of interspecific interactions and other nonhabitat factors on animal populations is recognized (Flather and Hoekstra 1985), information that permits consideration of such factors is limited and, therefore, rarely incorporated into analytical models.

Habitat-based models have several characteristics that make them conducive to large-scale analyses of shifting patterns in land use and land cover. First, habitat is easily inventoried relative to inventories of wildlife populations, and several databases support regional descriptions of land use and land cover. Second, habitat-based models establish a direct link between wildlife populations and the entity altered by land management activities: their habitat.

Habitat-based models provide measures of habitat suitability or some estimate of population level or density. Habitat suitability models are the most common and tend to be based on expert knowledge of a species' natural history. Models developed by the USDI Fish and Wildlife Service (1980) (HEP), Boyce (1977) (DYNAST), and the U.S. Army Corp of Engineers (1980) (HES) are typical examples of this approach. However, it has been difficult to establish verifiable relationships between habitat suitability and observed wildlife numbers (Cole and Smith 1983, Lancia et al. 1982).

Less commonly, some habitat-based models predict population levels or abundance classes directly from characteristics of the habitat. Outputs expressed in animal numbers are necessary to understand wildlife use implications and opportunities, since animals are the resource used and perceived by people; habitats are difficult to interpret in those respects. The habitat-population relationships tend to be empirically derived rather than mechanistic, functional relationships. For example, Williams et al. (1977) developed a method based on pattern recognition principles that predicts an expected long-term population level for a particular area. A more rigorous extension of pattern recognition principles entails the use of multivariate statistical techniques. Multivariate procedures are acknowledged as a suite of methods that inherently fit habitat evaluation problems (Shugart 1981).

Although habitat-based population analysis techniques are available, most have been developed and applied at the site-specific level. Geographic aggregation of results from site-specific models is impractical and inappropriate to produce regional-scale summaries for national assessments (Hawkes et al. 1983). Similarly, arbitrary application of a site-level model to a region as a whole is not recommended (Risser et al. 1984). Consequently, development of new wildlife models with inventory data consistent with the intended scale of application was required.

REGIONAL DEER AND TURKEY MODELS

The objective of the wildlife models was to develop a regional-level projection tool that could be used to assess potential impacts from land use shifts and forest management. Based on the geographic scale of interest and the constraint that there were no known functional relationships between wildlife and land base patterns at the regional scale, an empirical approach using multivariate statistical analyses was chosen. The approach, similar to that of Klopatek and Kitchings (1985), uses discriminant function analysis to establish the statistical relationships between land use and forest vegetation descriptors and relative abundance classes of white-tailed deer and wild turkey at the county level.

Land Area Database

County land area estimates by land use and land cover categories were obtained from the Soil Conservation Service (SCS) National Resource Inventory (NRI) (USDA Soil Conservation Service and Iowa State University Statistical Laboratory 1987) and the Forest Service (FS) Forest Inventory and Analysis (FIA) (USDA Forest Service 1985) regional surveys. Estimates of total county land and water area were obtained from the Bureau of Census (USDC Bureau of Census 1970). The FIA survey was used to obtain area estimates of commercial forestland for timber management types (natural pine, planted pine, oak-pine, upland hardwood, and lowland hardwood) and forest age class. The NRI was used to obtain estimates of all other land types (crop-, pasture-, range-, and urban-land uses). Combining FS and SCS inventories to characterize total county land area resulted in discrepancies when compared to Bureau of Census estimates of total county area. This discrepancy resulted because the two inventories are not mutually exclusive. Iterative proportional fitting (Deming and Stephan 1940) was used to adjust FS and SCS inventory data to more closely approximate the total county land area reported by the Bureau of Census.

The predictor variables used in the development of the wildlife models are defined in table 3. All land area

Table 3.—Definition of land use and land cover variables used to develop wildlife models.

Variable acronym	Variable definition
TOTCRP	total cropland acreages including estimates of row crops, close grown crops, horticultural crops, unplanted cropland, and other cropland
TOTPAST	total pastureland and rangeland acreages including estimates of pasture, range, and rotation hay and pasture
HUMAN	total acreages associated with human development including estimates of urbanland, roads, railroads, strip mines, and farm structures
NP	total acreage estimates of natural pine
	acreage estimates of natural pine by age class
NPA1	age class 1: 0 - 20 years
NPA2	age class 2: 21 - 50 years
NPA3	age class 3: 50 + years
PP	total acreage estimates of planted pine
	acreage estimates of planted pine by age class
PPA1	age class 1: 0 - 10 years
PPA2	age class 2: 11 - 30 years
PPA3	age class 3: 30 + years
OP	total acreage estimates of oak-pine
	acreage estimates of oak-pine by age class
OPA1	age class 1: 0 - 20 years
OPA2	age class 2: 21 - 50 years
OPA3	age class 3: 50 + years
UH	total acreage estimates of upland hardwood
	acreage estimates of upland hardwood by age class
UHA1	age class 1: 0 - 20 years
UHA2	age class 2: 21 - 50 years
UHA3	age class 3: 50 + years
LH	total acreage estimates of lowland hardwood
	acreage estimates of lowland hardwood by age class
LHA1	age class 1: 0 - 20 years
LHA2	age class 2: 21 - 50 years
LHA3	age class 3: 50 + years
AGE1	acreage estimates for age class 1 across all forest types (except PP)
AGE2	acreage estimates for age class 2 across all forest types (except PP)
AGE3	acreage estimates for age class 3 across all forest types (except PP)
HWAGE1	acreage estimates for age class 1 across hardwood types (OP, UH, LH)
HWAGE2	acreage estimates for age class 2 across hardwood types (OP, UH, LH)
HWAGE3	acreage estimates for age class 3 across hardwood types (OP, UH, LH)

variables are expressed as a proportion of a given county. Information on the size, shape, and distribution of the land area components was not available.

Wildlife Database

Abundance data for white-tailed deer and wild turkey were obtained from the Southeastern Cooperative Wildlife Disease Study, University of Georgia.[5] Maps depicting distribution and abundance of turkeys in 1980 and white-tailed deer in 1982 were used to categorize each county into one of three density classes: low, moderate, or high. Although a categorical wildlife response variable results in a coarse description of popuation-habitat relationships, such as an approach was deemed more appropriate than modeling actual population numbers, given the magnitude of potential error associated with region-wide population estimates and past difficulties associated with relating actual numbers to measures of habitat quality (Cole and Smith 1983, Lancia et al. 1982). Counties were assigned to density classes by taking an area weighted mean of mapped density classes within each county. Areas were estimated by planimetering density class boundaries within each county. A frequency distribution of the weighted mean densities was examined for natural breaks, which were used to define the density value cutpoints for high, moderate, and low density classes. The average midpoint density levels for all strata were as follows:

	White-tailed deer	Wild turkey
Low	9/sq. mile	3/sq. mile
Moderate	19/sq. mile	7.5/sq. mile
High	29/sq. mile	14/sq. mile

Computer-generated maps of these data were reviewed by state wildlife agencies. A total of 772 counties were used to develop the deer models, and 766 counties were used to develop the turkey models.

Model Development

Discriminant function analysis (Johnson and Wichern 1982) was used to develop the statistical relationships between land use and land cover descriptors, and density classes for deer and turkey. Our objective in using discriminant analysis was to generate classification rules that could be used to predict density class membership (low, moderate, or high) based on land base predictor variables. Counties served as the observational unit and, therefore, the set of objects to be classified. Model adequacy was based on classification accuracy as measured by the percentage of counties in the sample that were correctly classified by the sample classification functions. Separate models for six physiographic strata (mountain, piedmont, eastern coastal plain, mid-south coastal plain, Mississippi Valley, and western coastal plain and highlands) were developed for both deer and turkey (fig. 5). The stratification was based on the SCS Major Land Resource Area (USDA Soil Conservation

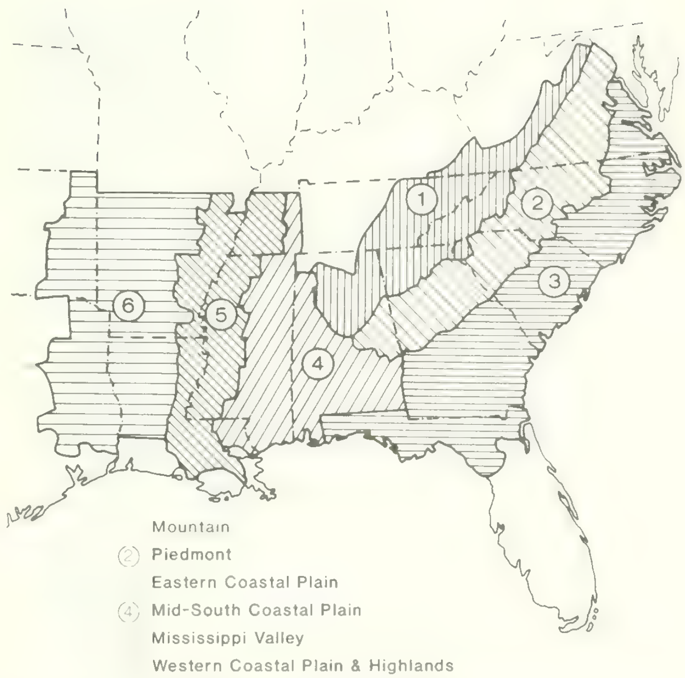

Figure 5.—Land base stratification for white-tailed deer and wild turkey models.

Service 1981). The models do not include peninsular Florida or the gulf coast counties of Texas and Louisiana because the small number of counties in these unique land types did not permit development of multivariate models. All calculations were performed using the Statistical Analysis System (SAS 1985a, 1985b).

Two assumptions critical to discriminant analysis are that the predictor variables be distributed multivariate normally within each classification group and the covariance structure between classification groups be similar (i.e., homogeneity of covariance) (Johnson and Wichern 1982). The assumption of multivariate normality is difficult to test directly. In practice, one has to be satisfied with subjecting each variable to univariate tests of normality (Habbema and Hermans 1977). Because all independent variables represented proportions, the normality assumption was violated by definition. All variables were transformed (arcsine [square root(x)]) prior to statistical analysis to more closely approximate a normal distribution. The UNIVARIATE procedure (SAS 1985b) was used to test each variable for univariate normality (Shapiro-Wilk statistic for $n < 50$; Kolomogorov statistic for $n > 50$). Testing for homogeneity of covariance resulted in rejection of this assumption in all cases—a common characteristic of ecological data (Williams 1983). Failure to meet this assumption resulted in the generation of classification rules based on quadratic discriminant functions rather than linear functions. Consequently, discrimination between classes is not based on means alone but considers differences in variances as well (Johnson 1981).

Selection of model variables was based on several criteria. Significant deviations from univariate normality resulted in elimination of variables from further consideration. In most cases, this resulted in the elimination of land base variables that were rare within a particular

physiographic stratum and, therefore, less likely to be of ecological significance in explaining distribution and abundance of a species within that physiographic stratum.

This initial subset of predictor variables was further reduced in three steps:

1. Examination of correlations among predictor variables resulting in the elimination of one of a pair of highly correlated variables. That variable presumed to be of greater ecological significance was chosen to remain in the model.
2. Insignificant ($p > 0.10$) results from univariate analysis of variance were used to flag variables for potential removal. Variables with insignificant ANOVA results were not automatically eliminated, however, because failure to establish univariate relationships does not preclude explanatory power under multivariate analysis.
3. Variables flagged in step 2 were then sequentially removed, and model performance (classification accuracy) was used to determine whether the variable was eliminated from the model.

This approach to variable selection was an attempt to maximize the classification accuracy of the model with the least number of predictor variables. Stepwise procedures were not used because of noted problems when the number of classification groups is larger than two—namely that the F-criterion emphasizes selecting variables associated with the best separated pair of classification groups, which can result in larger error rates (Habbema and Hermans 1977). The variable selection procedure included five to eight variables in the deer models (appendix A) and four to eight variables in the turkey models (appendix B). Tests for group differences based on the MANOVA results showed significant group differences ($p < 0.01$, Wilk's lambda).

A technical review committee comprised of three biologists from the South with knowledge of the species being modeled was assembled to evaluate model specification and performance. White-tailed deer and wild turkey habitat relationships established during model development were consistent with the review committee's expectation. White-tailed deer densities were negatively related to increased area of human-related land use. Cropland had a negative influence on deer density in areas dominated by agricultural land use (Mississippi Valley, western coastal plain and highlands). Cropland had a positive influence on deer density in the mountain stratum where forest cover dominated, presumably because of increased forestland/cropland edge habitat. Higher deer densities were also associated with early forest successional stages represented by young forest age classes.

Wild turkey densities were negatively associated with increased area in cropland and human-related land uses. Increased area in natural forest types, in particular upland and lowland hardwoods, and older age classes of hardwood types, were associated with higher turkey densities.

Model classification success rates for white-tailed deer and wild turkey averaged 79% and 82% region-wide. Classification success across strata ranged from 73% to 85% for white-tailed deer and 75% to 87% for wild turkey. Factoring out correct classifications attributable to chance showed that, across strata, the deer models performed 57% to 76% better than a random model, while the turkey models outperformed a random classifier by 61% to 72%. In all cases, the number of counties correctly classified was significantly better than a random model ($p < 0.001$, Kappa statistic) (Cohen 1968, Titus et al. 1984).

Although these classification accuracies indicate an overall good relationship to the data, accuracy measures based on data used to generate the models are likely to be optimistic. Jackknife estimation has been proposed as a less biased estimate of classification accuracy (Efron and Gong 1983, Johnson and Wichern 1982). The approach involves: holding one observation out; generating classification functions on the remaining observations; classify the "held-out" observation; repeat until each observation has been held out. Jackknifed estimates of region-wide model classification accuracy for white-tailed deer and wild turkey were 60% and 67%, respectively. Across strata, jackknifed estimates of accuracy ranged from 53% to 67% for deer and 60% to 77% for turkey.

MODEL APPLICATION

The models generated by the discriminant analysis were used to classify "new" counties; that is, counties where group membership was not known with certainty. "New" counties can be created by hypothetical or predicted changes in land use and land cover over the entire South.

In our application, shifts in the land base variables were predicted by the three land base area projection models in figure 4. Acreage projections of major land use categories (timber management type, cropland, pastureland/rangeland, urbanland) were made by econometrically based land area regression models (SAM) (Alig 1984). Regional changes associated with forest age class acreages were provided by TRIM (Tedder 1983, Tedder et al. 1987) and TAMM (Adams and Haynes 1980). In addition, SAM and TRIM described the forestland base by four ownership classes (national forest, other public, forest industry, and other private). Ownership categories permitted a more accurate representation of the land base by tracking ownership differences in timber management. Land bases were projected for the years 1985, 1990, 2000, 2010, and 2030.

The coupling of these models requires that wildlife model variables be consistent with the outputs provided by the inventory projection models. Although land base definitions are consistent, the models operated at different scales: TRIM provided forest age characteristics at the subregional level (Southeast and South-central), while SAM provided information at the state level. Since the wildlife models require county level information, the

projected changes in land area were used to adjust initial county level estimates of land use and land cover. This adjustment was accomplished through the iterative proportional fitting procedure described earlier and simulation of timber growth and harvest.

Wildlife responses to projected changes in land use and land cover patterns were assessed by calculating a region-wide weighted average density level for deer and turkey. Application of the discriminant function models produces a probability estimate of membership in each of the three density classes for each county. Averaged over all counties, these probabilities represent a regional probability for each density class. The regional probabilities calculated in this way provided the weights that were applied to the density level associated with each of the three density classes as follows:

$$D = p_l d_l + p_m d_m + p_h d_h$$

where D is the overall average density for the region, p is the mean posterior probability of membership in abundance class l (Low), m (Moderate), or h (High), and d is the midpoint density level associated with each abundance class.

For the application reported here, it was important to maintain a subregional level of geographic resolution. As described earlier, the two subregions in the South are the Southeast (Florida, Georgia, North Carolina, South Carolina, and Virginia) and the South-central (Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas). These subregions correspond to the geographic aggregations reported by TRIM and were important to the timber resource policy analysis being completed for the Southern forests (USDA Forest Service 1988). For this reason, the projected deer and turkey trends are discussed individually for both the Southeast and South-central subregions. Before discussing the application results, a review of model assumptions will provide a reference point for interpretation.

Ecological Assumptions

A number of assumptions were required to model the possible impacts of changing land use and forest vegetation characteristics on wildlife abundance. These assumptions acknowledge factors that influence wildlife numbers that currently could not be incorporated into the model. These assumptions form the context within which findings from the model can be interpreted, for they specify the limitations of current available information. Incorporation of these assumptions into regional models of wildlife abundance will require further research. The specific ecological assumptions made in this analysis were as follows:

1. Wildlife density estimates used in building the habitat relationship models were at the carrying capacity of the habitat. The regional habitat-based population models assume that similar patterns of land use and forest vegetation will support similar densities of deer and turkey. This is possible only if the observed density levels associated with each county are at or near the capacity of the habitat.
2. Wildlife population changes predicted over the projection period are due solely to changes in land use and forestland characteristics. Nonhabitat factors that influence deer and turkey density are assumed to remain constant across counties and over the projection period. For example, interspecific competition and predation rates are assumed constant. Similarly, factors that affect animal density attributable to wildlife management (such as harvest regulations, transplant programs) are assumed to continue in the future at a level practiced in the recent past. The relationship between harvest pressure and incidence of vehicle-kills, and human-related land use is assumed not to change across the region or over time.
3. Timber management activities will continue about as in the recent past and, therefore, will not effectively change wildlife population responses over the projection period. For example, management of pine plantations is assumed not to change in a way that will benefit wildlife (e.g., alter spacing of trees to make understory characteristics more favorable to certain wildlife species).
4. Patterns of landscapes (the size, shape, and distribution of land uses) will not change dramatically over the projection period. For example, there will not be a significant shift to large, consolidated cropland areas or significant increases in forestland fragmentation.
5. It was assumed that the average density level of deer and turkey for each time period was a function of land base characteristics and the proportion of counties predicted in each density class for the previous time period. Consequently, if the models predict an increase in the number of counties from one time period to the next, then the model will recognize an increased chance of classifying counties into the high density category in the next projection period.

We recognize that these are simplifying assumptions, but the data were not available to incorporate their influence in the habitat-population relationships or in projecting how they change over time. In addition, it should be emphasized again that the wildlife modeling effort represents an impact analysis that is entirely dependent upon the land use and timber inventory projections. Feedback mechanisms whereby the wildlife responses alter the timber resource and timber management, as well as explicit incorporation of the assumptions made here, are being considered for future research in regional wildlife habitat models.

Baseline Scenario

Possible impacts on wildlife resources resulting from land management activities were evaluated by running land area and timber inventory models assuming a likely future trend in land use and timber management. The assumptions made in the baseline analysis were devel-

oped from expert opinion on what the likely demand for timber products will be and what level of timber management would be required to ensure that timber supplies would meet that demand (USDA Forest Service 1988). This particular parameterization of the land base models provided a baseline condition for comparisons against alternative future scenarios.

Projected land area changes for the Southeast and South-central subregions between 1985 and 2030 are summarized in table 4. The projected trends indicate more intensive forest management and more human-dominated land uses. Forestland area in general, and to a lesser degree pastureland, decline over the projection period. Cropland shows slight gains, particularly in the South-central subregion. Human-related land uses show relatively large increases across both subregions. The most notable forest type changes projected were conversion of natural forest types to pine plantations. Natural pine accounts for the majority of the converted acres, but oak-pine and upland hardwood types also will be harvested and planted to pine. The major changes in forest stand structure involve gains in younger forest age classes in both subregions and increases in older age classes in the South-central.

White-tailed deer, a generalist in its habitat requirements, was predictably not explicit in its response to changes in any single land cover characteristic. The deer models project a density decline in both the Southeast and South-central for an average regional decline that approaches 20% (fig. 6). The decline was attributed to an overall loss of forest habitat, specifically upland hardwoods, and the conversion of natural pine and oak-pine stands to planted pine. Increased acreages in human-related uses, including urbanland and roads, also contributed to the overall decline in deer numbers. These uses directly reduce available habitat and are associated with increased mortality from associated disturbances (e.g., vehicle kills, hunting pressure).

Wild turkey have more specific habitat requirements than deer and are closely tied to the hardwood component of the forestland base. Increased human-related land

Table 4.—Projected land area changes (percent of total land base) in the South between 1985 and 2030.

	Southeast		South-central	
	1985	2030	1985	2030
TOTCRP	14.8	15.0	18.3	19.5
TOTPAST	12.9	12.1	17.9	15.4
HUMAN	8.9	12.5	6.0	10.0
TOTAL FORESTLAND	57.8	54.7	55.0	52.1
NP	14.4	7.2	11.0	6.1
PP	8.5	14.8	5.0	12.4
OP	6.6	6.7	9.7	6.6
UH	18.9	17.9	9.5	9.1
LH	9.2	8.1	9.5	9.1
AGE1	10.3	16.3	16.4	18.7
AGE2	23.8	13.0	31.1	11.3
AGE3	15.1	10.7	2.4	9.7
HWAGE1	6.6	12.7	12.2	15.1
HWAGE2	14.7	9.7	24.6	8.9
HWAGE3	13.5	10.3	2.1	9.7

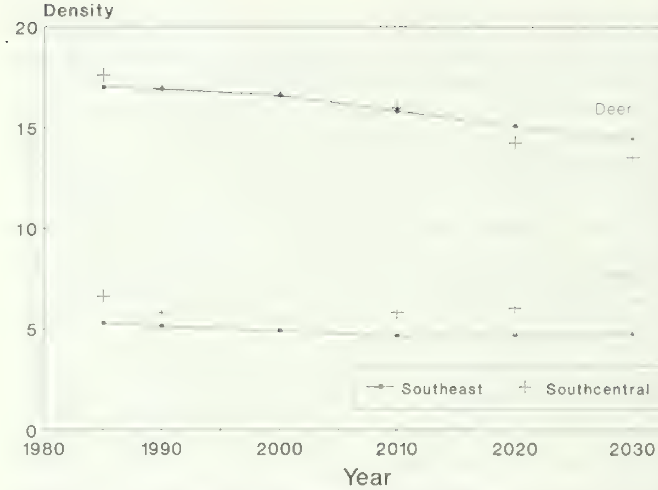

Figure 6.—Projected changes in white-tailed deer and wild turkey density (no./sq. mile) for the Southeast and South-central subregions.

use and the general loss of upland hardwood and oak-pine types contribute to the initial decline in the projection (fig. 6). After the year 2000, however, average turkey density levels off in the Southeast and recovers in the South-central in response to increased acres in older hardwood stands.

The greater decline in deer compared to turkey is likely a function of the distribution of density classes relative to private and federal land ownership. National forests constitute the majority of the federal lands across the South, with 24% of the counties containing some national forest land. Consequently, management on private land can have a significant impact on deer and turkey populations. Within those counties lacking national forest land, 56% support moderate to high deer densities, while only 37% support moderate to high turkey densities. Within counties containing national forest land, 27% support high turkey densities, while 14% support high deer densities. This pattern suggests that the projected intensification of land use and timber management on private lands can have a more negative impact on deer than turkey populations.

Alternative Scenarios

Fourteen alternative scenarios were defined in the timber resource policy analysis for the southern forests (USDA Forest Service 1988). The wildlife models were able to analyze potential impacts for the five alternatives that would change the commonly defined land base (see appendix C for a description of scenarios):

7. Increased Stumpage Costs
8. Reduced Timberland Area
9. Reduced Timber Growth
10. Reduced National Forest System Harvest
13. Economic Opportunities on Private Timberlands

Projections of deer and turkey density under each alternative show little deviation from the baseline condition. For both deer and turkey, the change in density over time is greater than the change between alternatives and the

baseline (appendix D). This is due, in part, to: (1) the alternatives were developed to test impacts on timber resources rather than to test land type changes that could be significant to deer and turkey distribution and abundance, and (2) the relatively small changes in the projected land base in the five scenarios analyzed. Scenarios 8 (Reduced Timberland) and 13 (Economic Opportunities on Private Timberlands) were the only alternatives that resulted in any change in land use or timber management types relative to the baseline. The remaining three scenarios only affected forest age class distributions.

To facilitate comparisons among scenarios, the wildlife responses and land base changes have been indexed. The index uses the 1985 wildlife density or land type proportion as the base and divides each subsequent projection period by the base. Consequently, the index should be interpreted as the change relative to 1985. Because of the limited variation in wildlife response across scenarios, only those scenarios that resulted in perceptible differences from the baseline will be discussed.

White-Tailed Deer Response to Alternatives

In the Southeast, the Reduced Timberland (8) scenario resulted in the greatest deviation in deer density from the baseline condition (fig. 7a). Deer decline less rapidly than in the baseline due to increased land type diversity associated with conversion of timberland to cropland. The loss in timberland acreages is distributed across all timber management types and age classes, resulting in small differences in type and age class patterns from the baseline. Human-related land uses and pastureland are unchanged from the baseline condition. Cropland is projected to increase from 14.9% to 19.3% of the total land base (fig. 7b). The Southeast is dominated by timberland cover, particularly in the mountain and, to a lesser degree, in the piedmont regions. Although information on the size, shape, and distribution of land use is not explicitly included in the deer models, the presumed fragmentation of the forestland base associated with this alternative would result in more favorable edge habitat conditions.

In the South-central subregion, deer density declines noted under the baseline were moderated under the Increased Stumpage Costs (7) and Economic Opportunities on Private Timberland (13) scenarios (fig. 8a). Land use changes (cropland, pastureland, rangeland, and human-related land uses) are unaltered from the baseline conditions. Deer density appears to be responding to

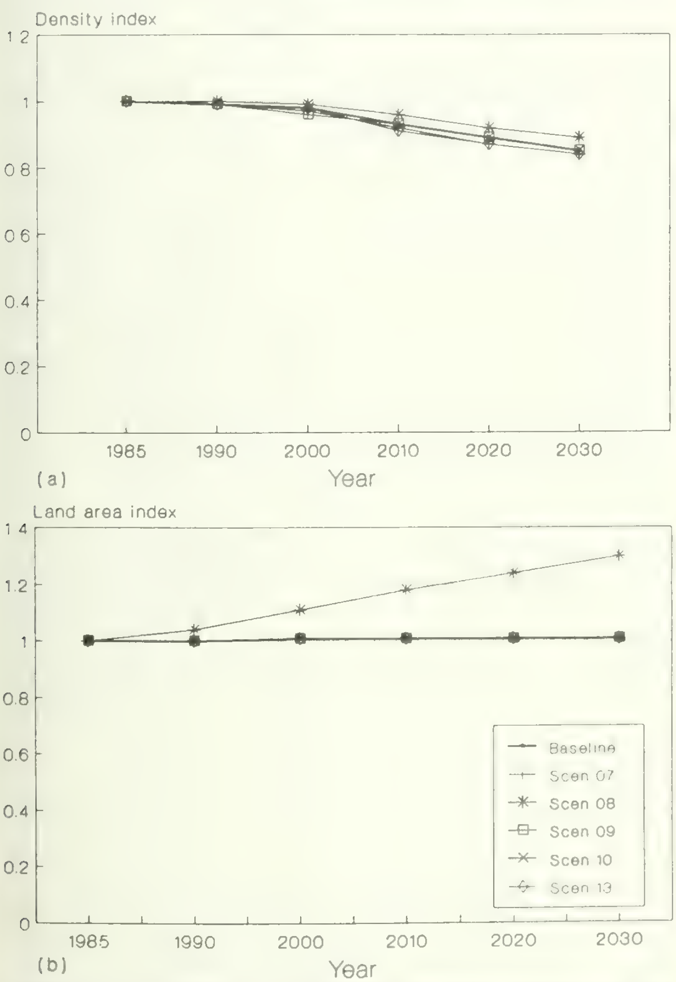

Figure 7.—Comparison of (a) indexed deer density response, and (b) indexed total cropland area change between the baseline and alternative land base scenarios in the Southeast subregion.

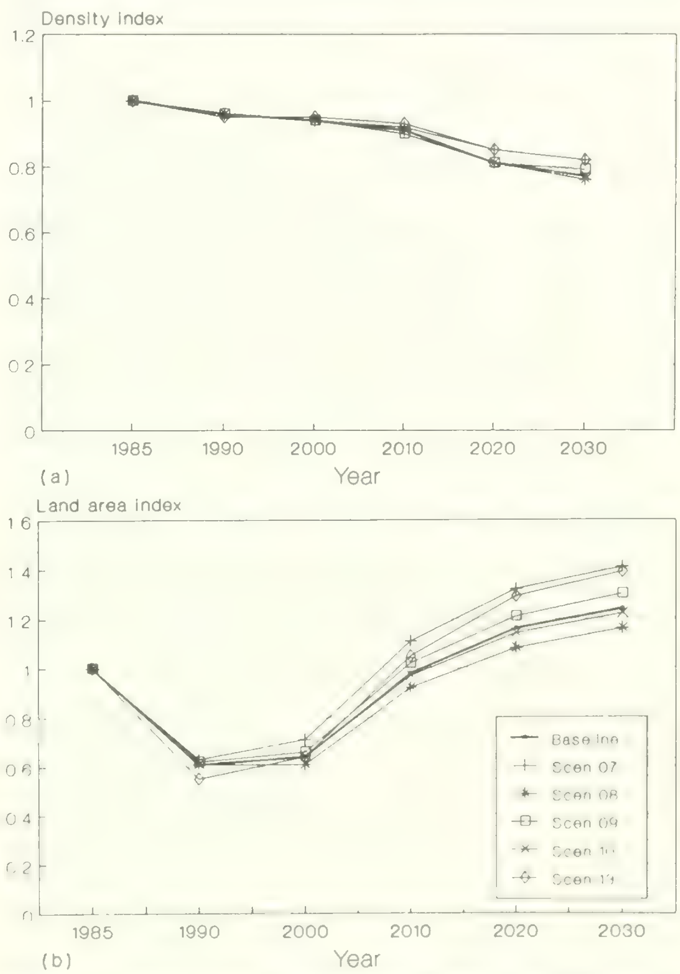

Figure 8.—Comparison of (a) indexed deer density, and (b) indexed younger hardwood (age class 1) area change between the baseline and alternative land base scenarios in the South-central subregion.

increased acreages associated with early forest successional stages as represented by younger-aged stands, particularly hardwood types. The South-central is currently dominated by medium-aged forest stands. As these stands move into the harvestable age classes, large increases in younger-aged stands as cutover acres are regenerated can be expected. Scenarios 7 and 13 resulted in the greatest increases in area of younger hardwood types (fig. 8b).

Wild Turkey Response to Alternatives

Wild turkey densities are, in general, less responsive to the alternative scenarios than are white-tailed deer. In the Southeast, wild turkey densities deviated only slightly from the baseline under the Reduced Timberland (8) and Economic Opportunities on Private Timberland (13) scenarios (fig. 9a). Under the Reduced Timberland alternative, turkey densities are projected to decline slightly more than under the baseline. The increased acres in cropland (fig. 7b) and the reduction in hardwoods, such as bottomland types (fig. 9b), contribute to this decline. The density decline is moderated slightly under an alternative of greater economic opportunities for timber on private lands. The land base changes under this alternative are similar to the Reduced Timberland (8) scenario with these noted exceptions: (1) natural forest types are converted to pine plantations rather than cropland, (2) natural pine and oak-pine stands contribute more to the lost acreages of forest types than do the hardwood types, and (3) there is a gain in younger hardwood stands which, in the early years of this age class, can provide grassy open areas used as nesting and brood-rearing habitat in a region already dominated by older-aged hardwoods.

South-central turkey densities were most responsive to the land base projection under the Economic Opportunities on Private Timberland (13) scenario (fig. 10a). The observed turkey density increase over the baseline appears to be a function of changes in age classes. Older age classes increase less relative to the baseline, but the increases are still substantial relative to 1985 (fig. 10b). Concomitantly, there is an increase in the younger age classes which, as described above, can provide grassy open areas for nesting and brood-rearing. The more equitable distribution between older and younger stands resulted in slightly greater densities of turkeys than observed under the baseline.

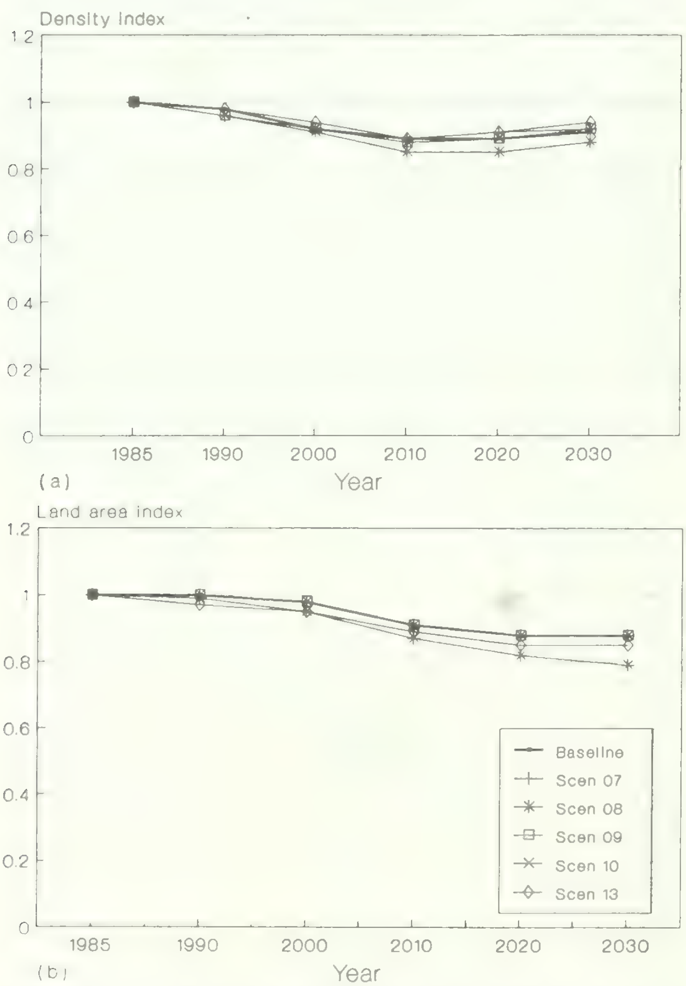

Figure 9.—Comparison of (a) indexed turkey density response, and (b) indexed area change for lowland hardwoods between the baseline and alternative land base scenarios in the Southeast subregion.

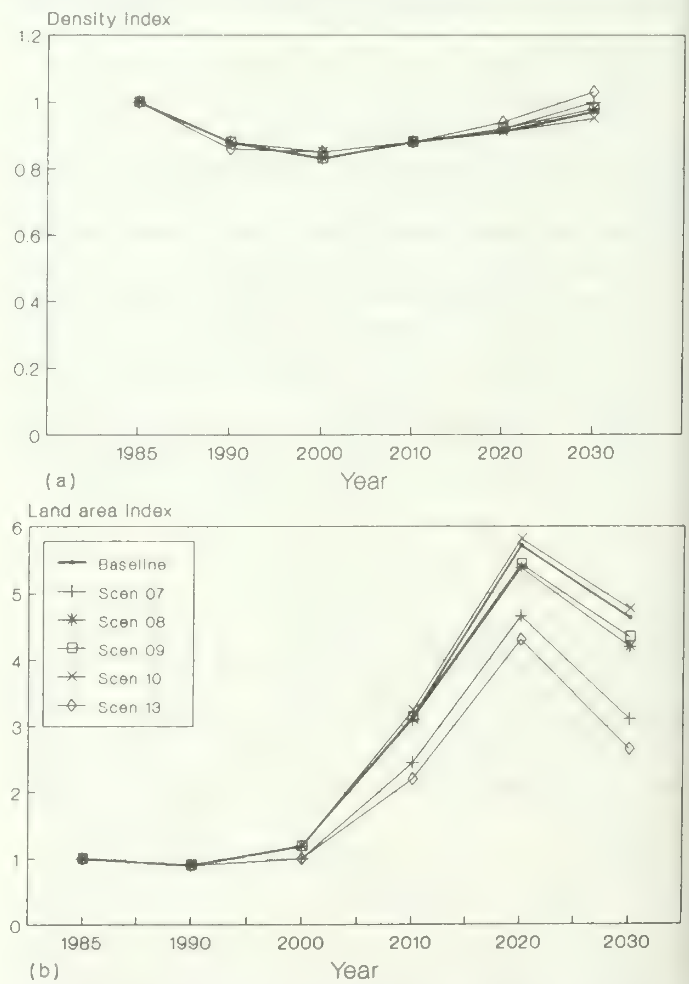

Figure 10.—Comparison of (a) indexed turkey response, and (b) indexed area change for hardwood age class 3 between the baseline and alternative land base scenarios in the South-central subregion.

MANAGEMENT AND RESEARCH IMPLICATIONS

Management Implications

The white-tailed deer and wild turkey models were designed to evaluate the possible effects of changing land use and timber management on a regional scale. The models represent empirical relationships between habitat (as represented by the proportion of land in various uses and timber cover at the county level) and observed deer and turkey density. Under a future of increased urbanization and more intensive timber management, white-tailed deer and wild turkey were projected to decline over a 50-year planning period. However, the models project what may occur if no wildlife management activities are directed at altering or mitigating the projected trends. Current management practices for deer and turkey, including harvest regulation and habitat management activities, are implicit in the model and assumed to remain constant over the planning period. For this reason, the baseline scenario does not necessarily reflect the future of the deer and turkey resource in the South; certainly, state and federal agencies have the option to intensify deer and turkey management to offset perceived declines. Similarly, private land owners may find increased economic incentive (access fees, hunter lease agreements) to manage their lands for wildlife production.

Because the observed changes in the land base across time are, in general, much greater than those among scenarios, projected deer and turkey density trends do not vary much from the baseline condition. For the application reported here, the projected baseline changes in deer and turkey densities are more critical in specifying potential management opportunities than the analysis of alternative scenarios. Over the projection period, the most notable change in timberland is the conversion of natural forest types to pine plantations. The majority of the increased acreage in planted pine will come from natural pine stands, although substantial acreages of mixed pine-hardwood and upland hardwoods also will be converted. The most important land use change will be the significant increase in human-related land uses—increasing by 66% over the planning period.

The projected increases in human-related land uses suggest that management consider activities to control for direct losses of habitat through urbanization and increased disturbance associated with increasing human populations. Management activities that control deer and turkey harvest, accessibility of lands to human use, and incentive programs to private land owners can help maintain deer and turkey populations into the future.

Similarly, implementation of region-wide forest management practices to mitigate the impacts associated with intensive management for softwood production could improve future deer and turkey populations. Controlling the spacing within pine plantings, maintaining hard and soft mast-producing plant species, and specifying the size, shape, and distribution of clearcuts will all help mitigate deer and turkey declines.

Intensification of forest management activities must also consider the likely increased costs to manage wildlife. Funding through federal programs may help compensate for increased wildlife management costs. However, given the potential for declining deer and turkey populations and the crowding of hunters on a shrinking habitat base, one must consider the possibility of declining revenues from license sales and matching Pittman-Robertson funds. Human populations are expected to expand and land use is expected to intensify across the South. Unless the trends reviewed here change, state wildlife managing agencies could be faced with the challenge of solving increasingly complex management problems with a diminished financial base.

The deer and turkey models reviewed here do not address site-specific management recommendations. The models were developed to analyze potential impacts from broad land management activities, such as land use conversions, timber type conversions, or increased harvest of certain forest age classes. As such, the models provide a point of reference for evaluating and recommending future region-wide management activities.

Research Opportunities

The purpose for developing regional deer and turkey models was to provide results from which planners and policy makers could evaluate the potential impacts from changes in land use and timber management activities. The wildlife models, in conjunction with the other resources specified in the multiresource framework, represent an initial effort to quantitatively incorporate wildlife into a joint analysis of natural resource management over a large geographic region. The analysis discussed here represents a first-generation effort and many simplifying assumptions where necessary. Now that a conceptual framework has been specified and applied, there is a basis for recommending future research activities that will permit explicit incorporation of the assumptions made in this analysis.

One of the most important and difficult future research opportunities is the incorporation of resource feedbacks. The current multiresource framework only addresses the impacts of land use and timber management on wildlife; other resource interactions are not considered. Modification of the timber growth and yield functions based on changes in wildlife populations or wildlife management would initiate an evolution toward a truly interactive analysis and improve the capability to represent the complexity of multiple resource systems.

From the standpoint of wildlife habitat relationships, there is a need to incorporate the effect of size, shape, and distribution of land types on wildlife populations. Theory and empirical evidence have shown that the size and juxtaposition of different land units is important in explaining variation in the distribution and abundance of wildlife species. Incorporating such features, however, will require land base inventories and models that measure and project landscape patterns at the regional level.

There is also a need to more rigorously validate and verify current models. Validation, or the testing of the

model on independent data, is particularly difficult given the scale of the analysis and the fact that wildlife projections represent future conditions. Although historical data may provide an opportunity for validation, data on wildlife populations and land base characteristics over a sufficiently large geographic area are rare and usually not temporally congruent. These characteristics limit the current capability to validate the models reported here and force reliance on model verification to evaluate model performance.

Verification is the process of determining if the models produce reasonable results. Included in model verification is the sensitivity of model output to input uncertainty. There are two sources of input uncertainty within the modeling framework used here: (1) in the inventory data used to generate the population-habitat relationships, and (2) in the output from the land area and timber inventory models that provided input to the wildlife models during the projection process. When the estimated classification accuracies are considered in conjunction with the relatively low sensitivity to land base changes across alternative scenarios, the question arises: What constitutes a significant change in predicted regional densities? Analysis of uncertainty in inventory data and how uncertainty is propagated through a network of resource models are areas of future research that will provide insights into precision of model predictions.

CONCLUSIONS

Since the turn of the century, white-tailed deer and wild turkey populations have recovered dramatically from historic lows caused by exploitation and habitat degradation. In the South, current population estimates for deer and turkey are 29 and 47 times the nationwide population estimates for the early 1900's. Although intensive wildlife management for these species through protection and restocking programs contributed to the recovery, land use changes during this period provided the necessary habitat. Over the last 20 years, populations have continued to increase. Much of the increase in recent years appears to be occurring on private lands; deer and turkey population trends on public lands have leveled off. As in the past, future trends will depend, in part, on how lands in the South are used. Although alternative timber projections do not suggest large acreages will become deforested, more subtle but significant timber type conversions are projected. These large-scale timber type changes, together with increased urbanization, could significantly affect deer and turkey population levels.

Habitat-based population models were developed for deer and turkey in order to evaluate the potential impacts from projected changes in land use and timber management. Discriminant function relationships for six physiographic strata established empirical relationships between deer and turkey density classes and land base descriptors at the county level. Projections of increased urbanization and more intensive timber management for softwood production would likely lead to South-wide declines in deer and turkey densities.

Analysis of alternative land base descriptions showed similar trends in deer and turkey densities. The alternatives were designed to evaluate changes related to the timber resource not the wildlife resource. Consequently, deer and turkey population changes over time under the baseline condition were more valuable in evaluating future forest management policies.

The implications of the projected wildlife trends are logical. More intensive land use from human development or timber production will require more intensive wildlife management. Wildlife management practices that can ameliorate the effects of converting natural forest types to pine plantations could mitigate the projected declines. Similarly, wildlife harvest regulations, or controlling accessibility, could help offset the impacts associated with increasing human populations. In addition, economic incentives that promote favorable deer and turkey habitat on private lands could improve the trends reported here. Consequently, the deer and turkey declines are not what necessarily will occur but what may occur if consideration for these species is not included in managing the South's renewable resources.

The regional wildlife analysis presented here improves our capability to assess wildlife resources over large geographic areas. As part of a multiple resource modeling framework, impacts from changing land use and timber management can be examined simultaneously among other resources. Although several simplifying assumptions were made in the analysis, the feasibility of developing a regional analysis system from existing land base inventories was demonstrated. A conceptual framework and successful application provide a basis for recommending and incorporating wildlife interactions to achieve a more complete analysis of multiple resource questions.

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APPENDIX A

White-tailed deer discriminant function analysis by stratum: (a) mean (standard error) transformed value of each predictor variable for each deer density class, and (b) classification summary table depicting the number (percent) of counties observed in each density class (rows) and model-predicted density class membership (columns).

STRATUM: Mountain

a.

	Deer density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.178	(0.010)	0.198	(0.021)	0.256	(0.024)
HUMAN	0.275	(0.012)	0.266	(0.011)	0.264	(0.015)
UH	0.733	(0.025)	0.731	(0.027)	0.649	(0.032)
AGE1	0.369	(0.019)	0.291	(0.030)	0.327	(0.041)
AGE2	0.583	(0.015)	0.483	(0.020)	0.560	(0.018)
AGE3	0.394	(0.027)	0.544	(0.039)	0.420	(0.043)

b.

From	To class		
class	Low	moderate	High
Low	54 (87)	5 (8)	3 (5)
Moderate	8 (23)	25 (71)	2 (6)
High	5 (26)	2 (11)	12 (63)

Reclassification accuracy: 79%

STRATUM: Piedmont

a.

	Deer density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.308	(0.021)	0.267	(0.014)	0.357	(0.038)
HUMAN	0.386	(0.026)	0.291	(0.011)	0.240	(0.012)
UH	0.551	(0.018)	0.523	(0.013)	0.487	(0.021)
AGE1	0.353	(0.011)	0.430	(0.013)	0.442	(0.022)
AGE2	0.537	(0.015)	0.587	(0.012)	0.602	(0.027)
AGE3	0.369	(0.015)	0.317	(0.016)	0.337	(0.025)

b.

From	To class		
class	Low	moderate	High
Low	30 (65)	12 (26)	4 (9)
Moderate	9 (10)	76 (85)	4 (4)
High	2 (10)	3 (14)	16 (76)

Reclassification accuracy: 78%

STRATUM: Eastern Coastal Plain

a.

	Deer density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.455	(0.019)	0.489	(0.022)	0.455	(0.039)
HUMAN	0.264	(0.011)	0.223	(0.009)	0.203	(0.012)
UH	0.307	(0.011)	0.393	(0.016)	0.395	(0.032)
AGE1	0.350	(0.006)	0.395	(0.011)	0.406	(0.018)
AGE2	0.528	(0.009)	0.532	(0.012)	0.550	(0.029)
AGE3	0.323	(0.010)	0.364	(0.013)	0.363	(0.029)

b.

From	To class		
class	Low	moderate	High
Low	110 (83)	21 (16)	2 (2)
Moderate	18 (28)	41 (64)	5 (8)
High	0 (0)	4 (20)	16 (80)

Reclassification accuracy: 77%

STRATUM: Mid-South Coastal Plain

a.

Variable	Low Mean	Low (SE)	Moderate Mean	Moderate (SE)	High Mean	High (SE)
	Deer density class					
TOTCRP	0.488	(0.029)	0.335	(0.018)	0.354	(0.027)
HUMAN	0.239	(0.008)	0.223	(0.008)	0.182	(0.008)
UH	0.498	(0.030)	0.413	(0.016)	0.403	(0.016)
AGE1	0.510	(0.015)	0.632	(0.015)	0.584	(0.016)
AGE2	0.477	(0.024)	0.479	(0.019)	0.547	(0.013)
AGE3	0.136	(0.023)	0.129	(0.013)	0.165	(0.016)

b.

From class	To class Low	To class moderate	To class High
Low	18 (78)	4 (17)	1 (4)
Moderate	3 (5)	47 (85)	5 (9)
High	0 (0)	4 (15)	22 (85)

Reclassification accuracy: 84%

STRATUM: Mississippi Valley

a.

Variable	Low Mean	Low (SE)	Moderate Mean	Moderate (SE)	High Mean	High (SE)
	Deer density class					
TOTCRP	0.834	(0.054)	0.861	(0.048)	0.578	(0.044)
HUMAN	0.233	(0.016)	0.217	(0.009)	0.203	(0.013)
UH	0.178	(0.032)	0.156	(0.033)	0.304	(0.036)
AGE1	0.305	(0.026)	0.346	(0.022)	0.513	(0.021)
AGE2	0.325	(0.032)	0.349	(0.022)	0.467	(0.022)
AGE3	0.107	(0.025)	0.075	(0.020)	0.139	(0.020)

b.

From class	To class Low	To class moderate	To class High
Low	16 (57)	9 (32)	3 (11)
Moderate	4 (14)	22 (76)	3 (10)
High	1 (3)	5 (14)	29 (83)

Reclassification accuracy: 73%

STRATUM: Western Coastal Plain & Highlands

a.

Variable	Low Mean	Low (SE)	Moderate Mean	Moderate (SE)	High Mean	High (SE)
	Deer density class					
TOTCRP	0.233	(0.034)	0.181	(0.025)	0.133	(0.030)
HUMAN	0.205	(0.013)	0.208	(0.011)	0.189	(0.005)
UH	0.430	(0.030)	0.532	(0.026)	0.425	(0.027)
AGE1	0.569	(0.023)	0.495	(0.015)	0.640	(0.022)
AGE2	0.468	(0.030)	0.543	(0.020)	0.598	(0.029)
AGE3	0.110	(0.022)	0.182	(0.018)	0.175	(0.022)

b.

From class	To class Low	To class moderate	To class High
Low	18 (86)	2 (10)	1 (5)
Moderate	7 (16)	35 (78)	3 (7)
High	0 (0)	0 (0)	21 (100)

Reclassification accuracy: 85%

APPENDIX B

Wild turkey discriminant function analysis by stratum: (a) mean (standard error) transformed value of each predictor variable for each turkey density class, and (b) classification summary table depicting the number (percent) of counties observed in each density class (rows) and model-predicted density class membership (columns).

STRATUM: Mountain

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.192	(0.009)	0.237	(0.023)	0.099	(0.032)
HUMAN	0.277	(0.010)	0.273	(0.015)	0.201	(0.021)
UH	0.721	(0.021)	0.676	(0.027)	0.847	(0.050)
AGE1	0.344	(0.018)	0.359	(0.034)	0.221	(0.032)
AGE2	0.578	(0.014)	0.492	(0.020)	0.503	(0.035)
AGE3	0.406	(0.024)	0.461	(0.042)	0.704	(0.043)

b.

From class	To class Low	moderate	High
Low	73 (96)	3 (4)	0 (0)
Moderate	11 (35)	19 (61)	1 (3)
High	0 (0)	0 (0)	9 (100)

Reclassification accuracy: 87%

STRATUM: Piedmont

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.327	(0.016)	0.284	(0.020)	0.226	(0.018)
HUMAN	0.370	(0.015)	0.260	(0.012)	0.217	(0.009)
UH	0.502	(0.010)	0.562	(0.016)	0.547	(0.027)
AGE1	0.375	(0.009)	0.441	(0.018)	0.471	(0.023)
AGE2	0.554	(0.012)	0.569	(0.017)	0.631	(0.018)
AGE3	0.333	(0.013)	0.321	(0.023)	0.325	(0.026)

b.

From class	To class Low	moderate	High
Low	75 (84)	9 (10)	5 (6)
Moderate	11 (27)	25 (61)	5 (12)
High	6 (18)	1 (3)	27 (79)

Reclassification accuracy: 78%

STRATUM: Eastern Coastal Plain

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.521	(0.015)	0.336	(0.029)	0.299	(0.043)
HUMAN	0.253	(0.009)	0.232	(0.017)	0.224	(0.018)
UH	0.321	(0.010)	0.376	(0.022)	0.418	(0.038)
AGE1	0.362	(0.006)	0.388	(0.012)	0.382	(0.022)
AGE2	0.519	(0.008)	0.547	(0.014)	0.594	(0.021)
AGE3	0.326	(0.009)	0.363	(0.017)	0.387	(0.019)

b.

From class	To class Low	moderate	High
Low	145 (93)	7 (4)	4 (3)
Moderate	13 (33)	26 (65)	1 (3)
High	4 (19)	1 (5)	16 (76)

Reclassification accuracy: 86%

STRATUM: Mid-South Coastal Plain

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.450	(0.028)	0.378	(0.021)	0.313	(0.024)
HUMAN	0.237	(0.008)	0.230	(0.009)	0.181	(0.007)
UH	0.507	(0.032)	0.397	(0.017)	0.423	(0.014)
AGE1	0.547	(0.024)	0.593	(0.015)	0.626	(0.018)
AGE2	0.473	(0.025)	0.485	(0.018)	0.528	(0.020)
AGE3	0.104	(0.024)	0.142	(0.015)	0.162	(0.012)

b.

From class	To class Low	To class moderate	High
Low	17 (74)	2 (9)	4 (17)
Moderate	5 (10)	37 (76)	7 (14)
High	1 (3)	7 (22)	24 (75)

Reclassification accuracy: 75%

STRATUM: Mississippi Valley

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.799	(0.036)	0.810	(0.055)	0.551	(0.076)
HUMAN	0.219	(0.007)	0.223	(0.020)	0.204	(0.020)
UH	0.185	(0.026)	0.244	(0.045)	0.267	(0.048)
AGE1	0.341	(0.022)	0.409	(0.029)	0.509	(0.029)
AGE2	0.386	(0.021)	0.324	(0.031)	0.458	(0.033)
AGE3	0.126	(0.018)	0.054	(0.019)	0.134	(0.029)

b.

From class	To class Low	To class moderate	High
Low	40 (85)	5 (11)	2 (4)
Moderate	5 (21)	18 (75)	1 (4)
High	3 (14)	3 (14)	15 (71)

Reclassification accuracy: 79%

STRATUM: Western Coastal Plain & Highlands

a.

	Turkey density class					
	Low		Moderate		High	
Variable	Mean	(SE)	Mean	(SE)	Mean	(SE)
TOTCRP	0.214	(0.028)	0.199	(0.036)	0.101	(0.026)
HUMAN	0.212	(0.009)	0.210	(0.017)	0.192	(0.020)
UH	0.432	(0.022)	0.590	(0.050)	0.434	(0.023)
AGE1	0.565	(0.019)	0.514	(0.028)	0.539	(0.022)
AGE2	0.542	(0.020)	0.594	(0.024)	0.621	(0.028)
AGE3	0.155	(0.015)	0.205	(0.028)	0.267	(0.016)

b.

From class	To class Low	To class moderate	High
Low	38 (90)	2 (5)	2 (5)
Moderate	8 (44)	10 (56)	0 (0)
High	1 (8)	0 (0)	12 (9)

Reclassification accuracy: 82%

APPENDIX C

DESCRIPTION OF ALTERNATIVE SCENARIOS

1. Wharton growth assumptions with cycles. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by substituting the assumptions on population, gross national product, per-capita disposable income, housing, and other demand determinants, including economic cycles, contained in "Long-term Alternative Scenarios and 20-year Extension," Wharton Econometric Forecasting Associates, Vol. 3., No. 1, February 1985, for those contained in this study through 2005. For years after 2005, the assumptions used in this report were adjusted to be consistent with the Wharton 20-year trends and levels.

2. Improved processing efficiency. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by increasing lumber and plywood yields 15 percentage points above the 10% increase assumed in the base projections. The increase in yields will be staged in the progression 9%, 7%, 5%, 3%, and 1% per decade.

3. Fifteen percent softwood lumber tariffs. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by the imposition of a 15% ad valorem duty on softwood lumber imports effective in 1986.

4. High exports of timber products. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by increasing the projected exports of lumber, plywood, and pulpwood (including pulpwood and the pulpwood equivalent of pulp, paper, and board) by 20% in 1990, 40% in 2000, 60% in 2010, 80% in 2020, and 100% in 2030.

5. High imports of timber products. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by increasing the projected imports of plywood, pulpwood (including pulpwood and the pulpwood equivalent of pulp, paper, and board), and hardwood lumber and logs by 20% in 1990, 40% in 2000, 60% in 2010, 80% in 2020, and 100% in 2030.

6. Reduced U.S./Canadian exchange rate. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by reducing the U.S. exchange rate with Canada—U.S. dollars per Canadian dollar—to 0.80 in 1990, 0.85 in 2000, and 0.90 in 2030. In the basic assumptions, the exchange rate was assumed to be 0.86 in 1990, 0.95 in 2000 and 0.98 in 2030.

7. Increased stumpage costs. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by increasing stumpage prices above the base projections by 5% by 1990, 10% by 2000, 15% by 2010, and 20% by 2020.

8. Reduced timberland area. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by reducing the projected area in timberland in the South by 2 million acres in 1990, 5 million acres in 2000, and 11 million acres in 2030.

9. Reduced timber growth. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by reducing by 25% to net annual growth on pine plantations, natural pine, and mixed pine-hardwood stands shown in the empirical yield tables used in developing the base-level projections.

10. Reduced National Forest System harvest. The future as described by the basic and other specified and implied assumptions in this report, modified by reducing timber harvests on the national forests to 8.1 billion board feet in 1990 and maintaining this level through 2030.

11. Natural regeneration on cropland and pastureland. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by assuming that all the cropland and pastureland in the South that would yield higher rates of return in pine plantations would naturally revert to timberland by 2000 (70% natural pine, 30% hardwoods in the Southeast; 40% natural pine, 60% hardwoods in the South-central).

12. Economic opportunities on cropland and pastureland. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by assuming that all the economic opportunities (those that would yield 4% or more net of inflation or deflation) for establishing pine plantations on marginal cropland and pastureland would be utilized.

13. Economic opportunities on private timberlands. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by assuming that all the economic opportunities for increasing timber supplies on timberland in private ownerships that yield 4% or more net of inflation or deflation would be utilized.

14. Increased management intensity on forest industry timberlands in the Douglas-fir region. The future as described by the basic assumptions and other specified and implied assumptions in this report, modified by assuming that all the economic opportunities to increase timber supplies on forest industry timberlands in the Douglas-fir region would be utilized.

APPENDIX D

White-tailed deer and wild turkey density (number per square mile) responses to baseline and alternative scenarios.

White-tailed deer

	BASE	SCEN 07	SCEN 08	SCEN 09	SCEN 10	SCEN 13
			Southeast			
1985	17.0	17.0	17.0	17.0	17.0	17.0
1990	16.9	16.9	17.0	16.9	16.9	16.8
2000	16.6	16.5	16.9	16.4	16.6	16.6
2010	15.8	15.7	16.4	15.8	15.8	15.5
2020	15.1	14.8	15.7	15.1	15.1	14.8
2030	14.5	14.3	15.2	14.5	14.4	14.3
			South-central			
1985	17.6	17.6	17.6	17.6	17.6	17.6
1990	16.9	16.9	16.9	16.9	16.9	16.8
2000	16.5	16.6	16.6	16.5	16.6	16.7
2010	16.0	16.2	16.1	15.9	16.0	16.4
2020	14.3	14.9	14.3	14.3	14.2	15.0
2030	13.6	14.4	13.3	13.7	13.5	14.4

Wild turkey

	BASE	SCEN 07	SCEN 08	SCEN 09	SCEN 10	SCEN 13
			Southeast			
1985	5.3	5.3	5.3	5.3	5.3	5.3
1990	5.2	5.1	5.1	5.1	5.1	5.2
2000	4.9	4.9	4.8	4.9	4.9	5.0
2010	4.7	4.7	4.5	4.6	4.6	4.7
2020	4.7	4.8	4.5	4.7	4.7	4.8
2030	4.8	4.9	4.6	4.9	4.8	5.0

South-central

	BASE	SCEN 07	SCEN 08	SCEN 09	SCEN 10	SCEN 13
1985	6.6	6.6	6.6	6.6	6.6	6.6
1990	5.8	5.8	5.8	5.8	5.8	5.7
2000	5.5	5.5	5.6	5.5	5.5	5.6
2010	5.8	5.8	5.8	5.8	5.8	5.8
2020	6.0	6.1	6.1	6.1	6.0	6.2
2030	6.4	6.6	6.5	6.5	6.3	6.8

Flather, Curtis H.; Hoekstra, Thomas W.; Chalk, David E.; Cost, Noel D.; Rudis, Victor A. 1989. Recent historical and projected trends in white-tailed deer and wild turkey in the southern United States. Gen. Tech. Rep. RM–172. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

An analysis of the historical and future status of white-tailed deer and wild turkey populations in the southern United States is presented. Habitat-based models that statistically relate deer and turkey densities to land use and forest cover at the county level are used to evaluate regional impacts from alternative timber management and land use projections.

Keywords: Regional model, multiple resource analysis, white-tailed deer, wild turkey, South, habitat model, statistical model

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526

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Forest Service Land Management Planners' Introduction to Linear Programming

Brian M. Kent

USDA Forest Service
General Technical Report RM-173

August 1989

Forest Service Land Management Planners' Introduction to Linear Programming

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Abstract

This report provides a detailed explanation of basic concepts of linear programming (LP) for forest planners and others who must use the technique to develop national forest land management plans. The role of LP in national forest planning analysis is presented. Basic algebraic concepts needed to understand LP are reviewed. The various components of an LP model are described and the advantages and limitations of the technique are discussed. Examples are presented in order to illustrate the technique, how it is used to formulate forest planning models, and how it is used in the Forest Service land management planning process. Procedures for solving LP models and the technique known as goal programming are also discussed. No prior background in LP is assumed on the part of the reader.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Forest Service Land Management Planners' Introduction to Linear Programming

Brian M. Kent

INTRODUCTION

The purpose of this training report is to provide a detailed explanation of the aspects of linear programming that must be understood if forest planners and other forest personnel are going to use the tool effectively in the development of national forest land use plans. The choice of topics[2] covered is directed to this end.

Linear programming (LP) is a member of a group of techniques or models known as mathematical programming techniques. Other members of this group include goal programming, which is a special case of LP, integer programming, and a variety of nonlinear programming models such as quadratic and geometric programming. All of these techniques are classified as optimization models in that they are designed to choose an "optimal" alternative from a set of possible or feasible alternatives. The optimal alternative is the one which yields the minimum or maximum value of some numerically measurable criterion of performance.

Each of these models is composed of a set of mathematical relationships which are functions of activities that comprise the alternatives. These relationships describe the criterion of optimality (objective function) and the set of feasible alternatives (constraints due to limitations of the system being modeled). In the linear programming model, all mathematical relationships are linear. In nonlinear programming models, one or more of the relationships are nonlinear.

Mathematical programming models are members of a larger group of techniques classified as operations research techniques. A precise definition of the term "operations research," and one that would be agreeable to all people, is difficult to state. One possible definition is that operations research techniques incorporate a scientific methodology for making decisions. Computer simulation, queuing theory, decision theory, and network analysis are other examples of operations research techniques.

Like operations research, the term "systems analysis" means different things to different people. Often the two terms are regarded as synonyms and that is the approach taken here.

The application of operations research techniques to the solution of real world problems first occurred during World War II in the areas of military planning and logistics. Since that time, applications have been developed in such disciplines as economics, statistics, and the social sciences.

For example, one important preliminary step in the implementation of any major project is development of a timetable, or schedule of activities, that must be completed to finish the project. A network analysis technique known as PERT (Program Evaluation and Review Technique) is often used in the development of such a timetable. The technique is also useful in helping to identify which activities or steps are critical in the sense that they must be completed on time for the overall project schedule to be met. These activities define what is known as the critical path.

The development of high-speed computers has been of fundamental importance to increasing application of operations research techniques to large scale real world problems. Consider linear programming, the operations research technique to which this report is devoted: The algorithm used to solve an LP problem is known as the simplex method. Because of the amount of computation, it would take several hours to manually solve a problem involving even three or four variables. Problems arising from development of multiple-use land management plans may involve hundreds or thousands of variables. Solution of such large problems by hand is clearly impossible. The only practical approach is use of a high-speed computer and the sophisticated solution algorithms on such a machine.

Note that "program" has different meanings. There are "mathematical programs" and "computer programs." In the former term, "program" can be regarded as a synonym for "planning," while in the latter case, "program" refers to a set of instructions to a computer written in a special computer programming language such as Fortran. Confusion on this dual usage of program is compounded by the fact that mathematical programming problems are solved with the aid of computer programs.

A FOREST SERVICE SYSTEMS ANALYSIS OR OPERATIONS RESEARCH APPROACH TO MULTIPLE USE PLANNING

One major problem facing the manager of wildlands is satisfying the growing demand of the American people for various products and experiences such lands can provide. Public lands, including the national forests, are being called on to satisfy a large proportion of these demands. The diversity of demands leads to conflict, one which increases both the difficulty and number of problems a manager faces. For example, certain interest

[2]*Certain important aspects of LP, most notably the dual problem and certain refined solution techniques, have been omitted. These topics are covered in one or more of several standard LP texts. The partial list of these may be found at the end of this text.*

groups favor a preservationist approach to land management that involves the designation of large areas of land as wilderness or national parks. These areas would be managed for the preservation of natural flora and fauna, while the production of most commodities would be deemphasized. On the other hand, other interest groups favor land management policies that enhance the production of commodities such as timber and forage (Kent 1980).

As managers address the problem of how to best satisfy these demands, they must determine the productive capabilities of the resources. This involves determining (1) the suitability of the area for producing the desired products/experiences and (2) the level or rate at which such products/experiences may be produced without destroying long-term productive potential. Unfortunately, determination of productive capabilities is complicated by poor understanding of the biological systems that comprise even a small wildland resource. As a result, impacts—especially long-term impacts—of some management strategies can be difficult to estimate. As an extreme example of this problem, some clearcuts have been conducted on poor site lands and regeneration has proved difficult, with the result that sites are unstocked for years after harvesting.

SYSTEMS ANALYSIS IN NATURAL RESOURCE MANAGEMENT

Because of problems like the ones discussed above, the development of a comprehensive, workable, and effective land management plan for a large wildland system such as a national forest is a very complex process. This complexity is reflected in the planning process outlined in Section 219.5, Regional and Forest Planning Process contained in the National Forest Management Act planning regulations.

It will be necessary to consider a large number of issues, demands, management strategies, and system responses to management. A great deal of data must be assimilated and a rational procedure for development and evaluation of alternative plans designed. Such plans must be developed in a way that ensures responsiveness to public issues and management concerns; utilization of the best technical information available; and most importantly, responsiveness to changes in the public issues, management concerns, and technical information (DeVilbiss and Lundeen 1978).

All these factors combine to create a situation where effective management is both important and difficult to accomplish.

Situations such as these lend themselves to the application of systems analysis techniques. While it is possible to develop effective land management plans without the aid of these techniques, experience of the Systems Application Unit for Land Management Planning (SAU-LMP) group and others has shown that such techniques are extremely useful in plan development. Linear programming (LP), in particular, has proved to be a useful analytical aid in this process. For a general discussion of how LP and other analytical aids have been used by the SAU-LMP group, the reader is referred to the guide developed by Betters (1977). "Linear Programming and the Planning Process" in this section describes one scheme for incorporating LP into the process of developing a forest plan.

While this report concentrates on application of LP to land management planning, it is important to realize that this technique has been applied to a wide variety of problems in forest or natural resource management. A search of the literature by Bare in 1971 produced 336 references containing applications of systems analysis techniques (Bare 1971). In 1973, Martin and Sendak published an annotated bibliography of 416 references of such applications (Martin and Sendak 1973), and as of 1976, there were 925 applications of these techniques to forest land management problems cited in the literature (Bare and Schreuder 1976).

This increase is a reflection of the effectiveness of these tools as aids to forest land management. The majority of these applications incorporate either LP, computer simulation techniques, or some combination of both. Reasons for the predominance of the use of LP techniques over other mathematical programming techniques are discussed in the Advantages and Disadvantages of Linear Programming section. As the need for such management increases, the importance of systems analysis techniques and management aids should also increase.

LINEAR PROGRAMMING AND THE PLANNING PROCESS

Section 219.5 of the NFMA planning regulations specifies the 10 minimum interrelated actions that comprise the planning process:

1. Identification of issues, concerns, and opportunities;
2. Development of planning criteria (general and evaluation criteria);
3. Inventory data and information collection;
4. Analysis of the management situation;
5. Formulation of alternatives;
6. Estimated effects of alternatives;
7. Evaluation of alternatives;
8. Selection of alternative;
9. Plan implementation; and
10. Monitoring and evaluation.

It is important to note that while some of these actions are sequential with respect to time, some occur at the same time and others are repeated throughout the planning process.

The above list of actions is certainly not the only possible approach utilized to develop a forest plan; it is, however, representative of the type of planning process required. Implementation requires a large number of diverse types of activities conducted by people possessing different expertise. For example, the work plan for the development of the Arapaho-Roosevelt National Forest Plan indicates at least 250 activities are required

o implement the NFMA process (DeVilbiss and Lundeen 1978).

Because of the need for different kinds of expertise, he formation of an effective interdisciplinary (ID) team s one of the most important steps in this process.

Members of this team must have a general understanding of the role of LP in the planning process, even though hey may not be directly involved with formulation and solution of the model. As Betters (1977) has pointed out, LP is only one of a number of analytical aids available for use in plan development. This would suggest, and correctly so, that formulation and solution of a linear program is only one aspect of the planning process. Unfortunately, there is a tendency to believe that "LP" and "planning" are synonymous. The formulation and solution of a linear program is often considered to be the same as the actual development of the plan. In reality, it is only one step, albeit an important one, in the overall planning process.

One way to clarify the role of LP in the planning process is by way of an example. A list of some principal planning activities and their association with the 10 major planning actions identified by the NFMA regulations is given in table 1 (adapted from DeVilbiss and Lundeen 1978). Activities directly associated with the linear programming phase of plan development are identified.

With the exception of "revise and amend forest plan," the LP-related activities occur in the middle of the planning process (see table 1). Consideration of the types of activities that come at the beginning and end of this process can shed light on the role of LP.

Activities associated with the first two NFMA actions are concerned with laying the groundwork for the plan. They are directed toward determination of the plan composition in that they identify, among other things, issues to be addressed, demands made on the forest, and management concerns. Results of these activities are major factors in the determination of the basic form the plan will take.

The activities that follow the "Estimated Effects of Alternatives" deal with selection, approval, and implementation of the preferred plan. This suggests that linear programming-related activities bridge the gap between determination of plan design, and selection and implementation of a preferred plan. In order to accomplish this, LP fulfills the following functions:

1. Information synthesis.—A representative model of any system as large and complex as a national forest must be capable of utilizing large quantities of information or data. For example, such data include commodity production rates or resource output coefficients for different management prescriptions. Linear programming synthesizes the data obtained by earlier activities in the "Inventory Data and Information Collection" segment of the planning process. (Material in quotes indicate separate activities discussed in table 1.) This information is utilized along with the results of the "Capability" and "Analysis area delineation" activities in formulation of the basic model. Feasible management activities as determined by the "Management prescription development" activity and "Resource output coefficients" as determined from the "Resource inventory" and "Suitability/capability" activities are incorporated. The "LP matrix generation" activity deals both with coefficient generation and with structuring and storing the model in the computer.

Table 1.—Some planning activities and their relationship with the NFMA planning actions.

Identification of Issues, Concerns and Opportunities
Public involvement
Issue strategies
Futures
Listing of issues
Management concerns
Interagency coordination
RPA/regional plan
Legal review (ongoing)
Research (ongoing)
Development of Planning Criteria
Process criteria
Decision criteria
Inventory Data and Information Collection
Resource inventory
Information systems design
Land stratification system[1]
Interagency coordination
Analysis of the Management Situation
Capability area delineation[1]
Resource output coefficients[1]
Suitability/capability analysis
Analysis area delineation[1]
Management prescription development[1]
Demand analysis
Model design[1]
LP matrix generation[1]
Supply analysis[1]
Projection of current management direction[1]
Alternative formulation[1]
Formulation of Alternatives
Public involvement
Alternative formulation[1]
Estimated Effects of Alternatives
Alternative analysis[1]
Cost-benefit analysis
Input-output analysis
Environmental impact analysis[1]
Evaluation of Alternatives
Comparative analysis of alternatives
Recommendation of preferred alternative
Draft environmental statement
Draft forest plan
Selection of Alternative
Public involvement
Recommendation of preferred alternative
Final environmental statement
Final forest plan
Plan Implementation
Monitoring and Evaluation
Monitor forest plan
Revise and amend forest plan[1]

[1] *Activity directly associated with linear programming.*

2. Allocation of resources.—Once the model is formulated, it may be solved using one of the computer software packages specifically designed for this purpose. (More on this later.) The solution consists of an allocation of resources [i.e., the number of acres managed by each management prescription and the quantity of products (timber, forage, water, sediment, etc.) produced]. Because of this, the LP model is often referred to as an "allocation model." Linear programming models may also be used to schedule management prescriptions and resource outputs over time. The solution provides the basis for a plan, although the plan is comprised of more than just this solution (see the Advantages and Disadvantages of Linear Programming section). Correct LP model formulation ensures that the solution will be consistent with the ecological capabilities of the land base. This is done, in part, by incorporating ecological limitations in the model in the form of constraints.

3. Alternative plan analysis.—Linear programming is a very useful aid in formulating and quantifying the outputs from each alternative plan considered, including the so-called "no action" or projection of the current management direction alternative. Since these results provide the basis for both the analysis of estimated effects and evaluation of tradeoffs between different alternatives, this step is vital to the development of a preferred alternative. Each time the model is reformulated or modified in any way and solved again, an alternative plan is generated. Examples of how this is done are presented in subsequent sections of this report. Operations researchers refer to these types of activities as sensitivity or post-optimality analysis. In the same way, LP may aid in revision of an existing forest plan so that it may respond to changing conditions.

While this discussion presents a simplified representation of the planning process, it shows how an LP model can be utilized to help formulate a land management plan based on information obtained in the early phases of the planning process. Since LP is one of the few techniques that can be used to organize and synthesize large amounts of information required to develop a land and resource management plan, it has proven to be an effective aid in past efforts. It is important to remember that both reliable data and correct model formulation are required.

COMPUTER PROGRAMS FOR SOLVING LP PROBLEMS

Mention has been made of computer software packages that can solve linear programming problems. A number of these are available at the Fort Collins Computer Center. These may be grouped into two categories. The first consists of packages that actually solve an LP problem using a modified form of the simplex method (see the Graphical Interpretation of the "Stocking a Ranch" Problem section for a brief introduction to the simplex method). Two packages, ILONA and FMPS (Functional Mathematical Programming System), are available but FMPS is used in most cases.

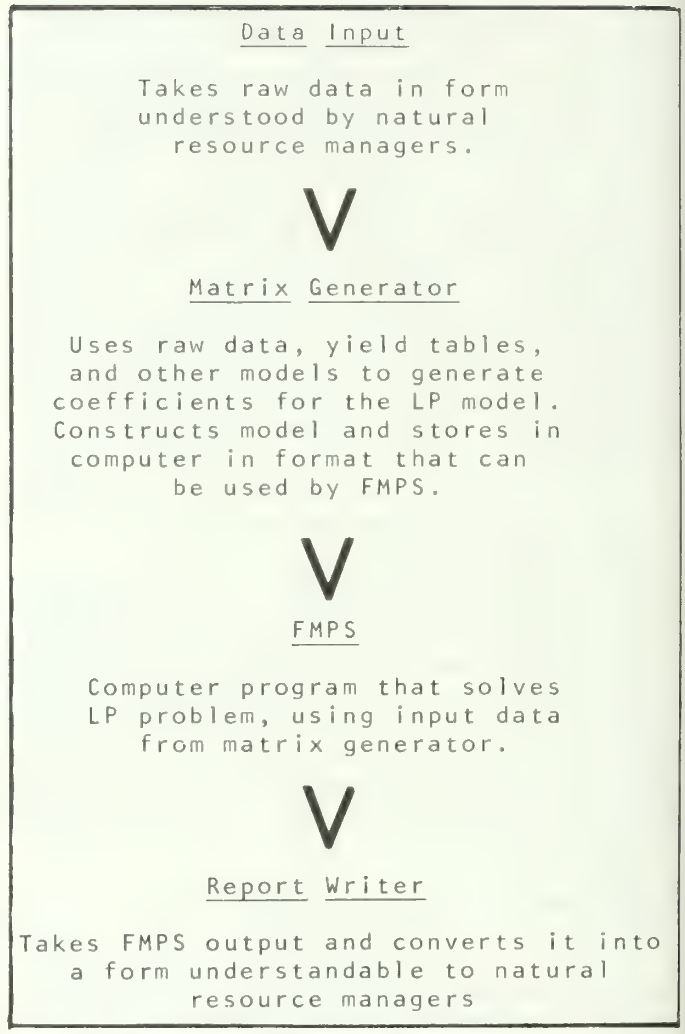

Figure 1.—Components of a typical LP package (including the FMPS solution package).

The second category is comprised of those packages that utilize user input data to structure the LP problem and then print out the results after the problem has been solved. A simplified diagram of the steps involved and the relationship between them and the solution package (in this case FMPS) is shown in figure 1. Forest Service packages in this second category include RCS (Resource Capability System), RAA (Resource Allocation Analysis), and FORPLAN (FORest PLANning model) for multiple use land management planning. Timber RAM (Resource Allocation Method) and MUSYC (Multiple Use Sustained Yield Calculation package) are Forest Service timber harvest scheduling packages. Timber RAM is a Model 1 formulation while MUSYC contains both Model 1 and Model 2. Roading RAM is an extension of Timber RAM that uses mixed-integer programming to incorporate road construction directly in the model. MAGE 5 is the matrix generator used in the RCS and RAA packages. Note that all of these packages use FMPS to solve the LP problem under consideration.

The remainder of this report is devoted to an elementary detailed coverage of LP. Additional insight into the role of linear programming in the planning process will be gained once the technique is understood.

REVIEW OF ELEMENTARY GRAPHICS AND PLOTTING (COORDINATE SYSTEMS)

In order to understand even a simple linear programming (LP) problem, certain fundamental concepts about coordinate systems and plotting of equations and inequalities must be understood. (This section of the report may be either skimmed or skipped if you are comfortable with this material. Most readers will probably find that they have been exposed to many of these concepts, but will find a review helpful.)

COORDINATE SYSTEMS—AN EXPLANATION

You are probably familiar with the concept of an x-y coordinate system. Such a system is used to assign an address, in the form of an x or a y coordinate value, to each point in a plane containing both an x and y axis. (Coordinate system is shown in fig. 2.)

Since it does not matter what the axes are named, we will change the name of the x axis to the x_1 axis and the y axis to the x_2 axis. This change is made to conform with standard linear programming notation (introduced later on). Each point on the plane defined by this coordinate system may be located or described by assigning values x_1 and x_2. The two axes divide the plane into four sections or quadrants. Each quadrant is characterized by the sign (negative or positive) of the values of x_1 and x_2 that corresponds to points in that quadrant. These signs may be determined by examining the signs of the values of x_1 and x_2 found on the portions of the axes bordering the quadrant.

For example, the first quadrant is bordered by the portion of the x_1 axis that has positive values for x_1 and by the portion of the x_2 axis that has positive value for x_2. Thus, all points in the first quadrant are characterized by the fact that they correspond to positive values for both x_1 and x_2. The values of x_1 and x_2 assigned to any point are called the coordinates of that point.

Points in the remaining three quadrants may be characterized in the same manner:

Quadrant	Sign of coordinate x_1	Sign of coordinate x_2
1	+	+
2	+	–
3	–	–
4	–	+

Plotting Single Points Corresponding to Constant Values

The point where the x_1 and x_2 axes intersect is called the origin and has coordinate values of $x_1 = 0$ and $x_2 = 0$. To find coordinates for any other point, draw a vertical line from the point to the x_1 axis and read off the value of x_1 at the point where the two lines intersect. Draw a horizontal line from the point to the x_2 axis and read off the value of x_2 at the point where the two lines intersect. Examples of this procedure are displayed in figure 3.

Plotting Points Corresponding to Constant Values for x_1 or x_2

Until now we have talked only about locating single points on a coordinate system. Let us consider the location of several points at the same time. As an example,

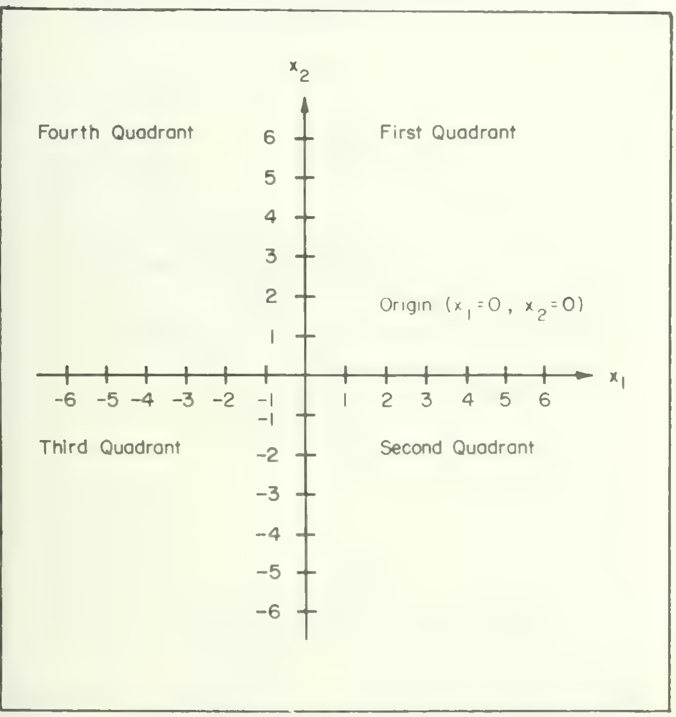

Figure 2.—An x_1, x_2 coordinate system.

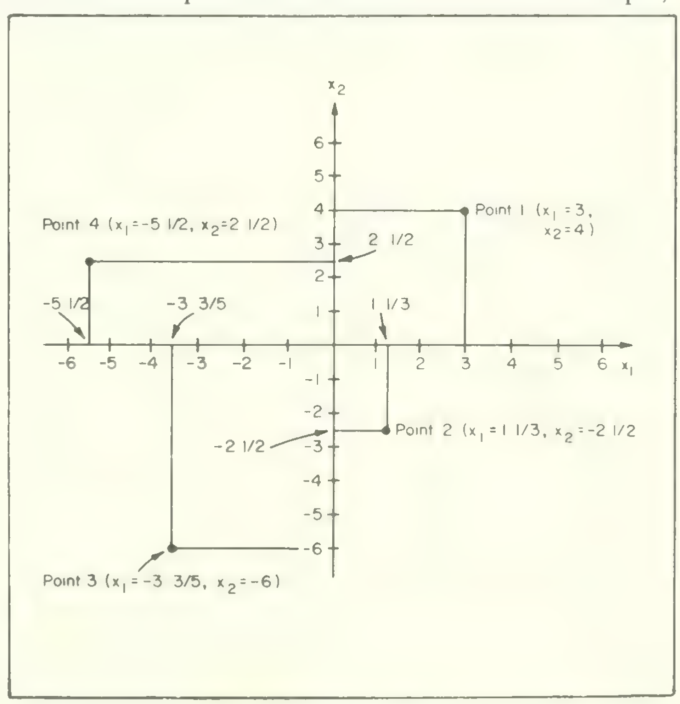

Figure 3.—Example of locating coordinates for four points on an x_1, x_2 coordinate system.

how would we locate all points which have an x_1 coordinate equal to 4? Before considering an answer to this question, we will simplify matters by restricting our consideration to the first quadrant only. The reason for this follows:

In an LP context, x_1 and x_2 are called *activity variables* or *decision variables* (more on this later). In any given linear programming problem, these variables have some physical interpretation such as the amount of some commodity or the number of acres on which particular management strategies are applied. For example, we might define them in this way:

x_1 = the number of acres on which spraying and seeding of rangeland is conducted; and

x_2 = the number of acres on which timber is harvested.

Clearly, it makes no sense to talk about a negative number of acres or a negative amount of some commodity. Since this will be the case for all activity variables associated with a land use planning linear program, we can ignore all quadrants except the first. In other words, we will never need to consider negative values of x_1 and x_2.

Now we will return to the question of how we might plot a coordinate system where the points have an x_1 coordinate of 4. Since we are only interested in the first quadrant, let us add the restriction that x_2 must be positive. A plot of the line representing all points that satisfy these restrictions is displayed in figure 4. Note that it consists of a vertical line intersecting the x_1 axis at the point $x_1 = 4$.

This general idea would hold for the plot of the set of points satisfying the requirements that $x_1 = c$, where c is any positive constant, and x_2 is positive. That is, the plot would be represented by a vertical line starting on the x_1 axis at the point $x_1 = c$.

Let us now consider plotting all the points that satisfy the requirements that $x_2 = d$, a positive constant, and x_1 is positive. By the way of specific example, consider the points satisfying $x_2 = 6$ and x_1 is positive. This plot is shown in figure 5. Note that it consists of a horizontal line intersecting the x_2 axis at the point $x_2 = 6$. For the arbitrary constant d, the corresponding plot would be a horizontal line intercepting the x_2 axis at the point $x_2 = d$.

Example 1.—Plot the points satisfying the following set of requirements:

$x_1 = 7$, x_2 positive;
$x_1 = 5\ 1/2$, x_2 positive;
$x_2 = 2$, x_1 positive;
$x_2 = 9$, x_1 positive.

The plots of these requirements are presented in figure 6.

INEQUALITIES: x_1 AND/OR x_2 ARE NOT CONSTANT VALUES

The material previously discussed deals with the plotting of relationships that specify that x_1 or x_2 are equal to some constant. Such a relationship is called an equality. Suppose that we wish to generalize this idea to consider cases where x_1 and/or x_2 are not restricted to being equal to some constant.

For example, consider x_1 and an arbitrary constant c. Two cases are possible:

1. x_1 is less than or equal to c;
2. x_1 is greater than or equal to c.

This type of relationship is known as an *inequality* and

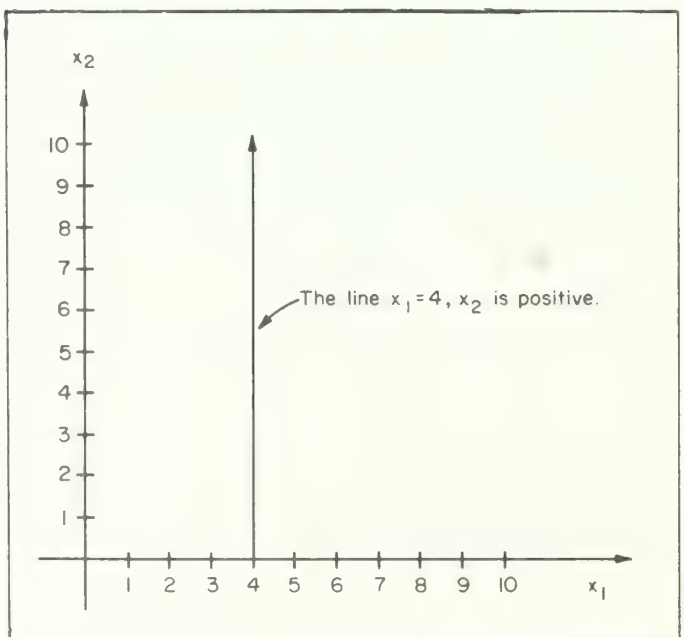

Figure 4.—Plot of a portion of the line segment representing the points that satisfy the requirements that $x_1 = 4$ and x_2 is positive.

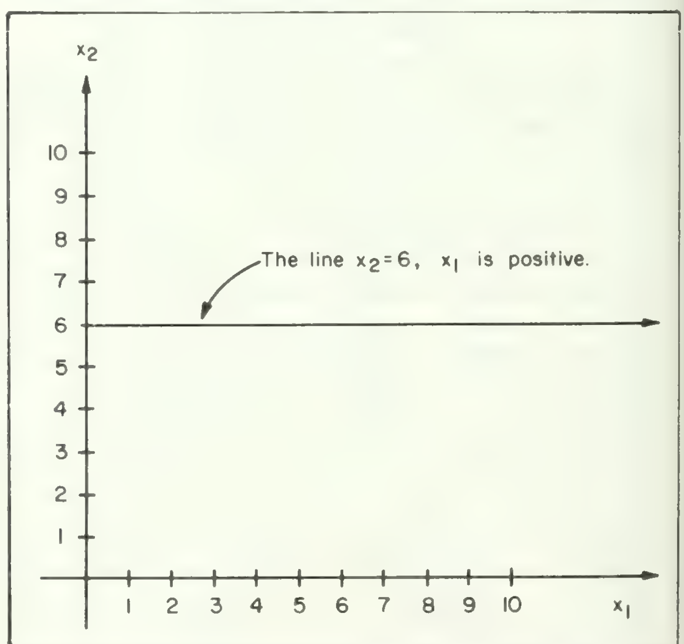

Figure 5.—Plot of a portion of the line segment representing the points that satisfy the requirement that $x_2 = 6$ and x_1 is positive.

it can be expressed mathematically with the aid of inequality symbols. These symbols are written as $\leq$ and $\geq$.

For the two cases listed above:

1. $x_1 \leq c$ (x_1 is less than or equal to c);
2. $x_1 \geq c$ (x_1 is greater than or equal to c).

Case 1 can also be stated in the form c is greater than or equal to x_1, and case 2 can also be stated in the form c is less than or equal to x_1.

The previous discussion pertains to the case which permits the two quantities x_1 and c to be equal. The symbols > and < are used to express relationships where the quantities x_1 and c can never equal each other. For example, the expression $x_1 < c$ means that x_1 is always less than c. Such relationships are called strict inequalities.

Plotting Inequality Relationships Involving a Single Variable

We have defined inequalities of the following forms:

$x_1 \leq c$
$x_1 \geq c$
$x_2 \leq d$
$x_2 \geq d$ where c and d are arbitrary constants.

Let us consider how we might plot the set of points that satisfy these relationships. To see how this is done, we will first consider a specific example with c = 4 and d = 6. That is, we are interested in the inequalities $x_1 \leq 4$, $x_1 \geq 4$, $x_2 \leq 6$, and $x_2 \geq 6$. As a first step, consider plotting the equalities $x_1 = 4$ and $x_2 = 6$ as we did above.

The line corresponding to $x_1 = 4$ is plotted in figure 7. Note that, as before, we are only interested in nonnegative values of x_1 and x_2 so that only the first quadrant has been plotted. Also note that, as indicated

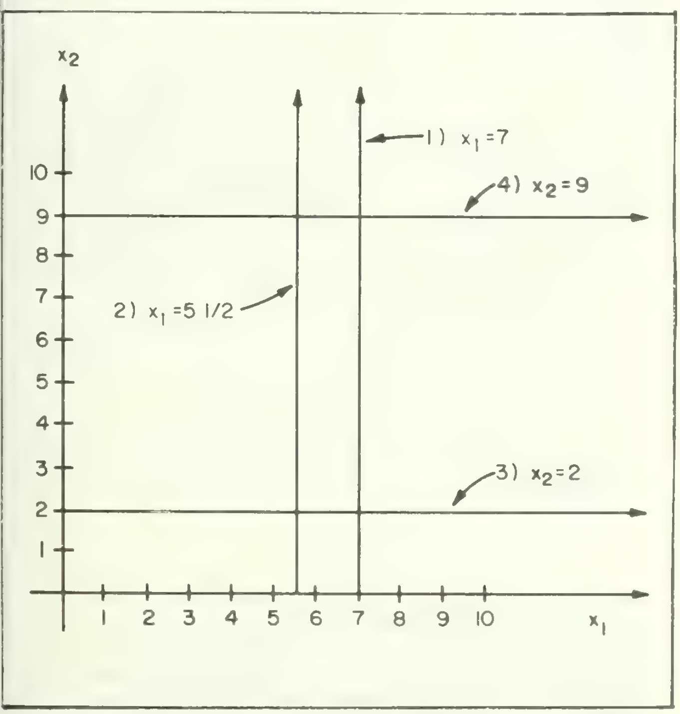

Figure 6.—Plots of the requirements specified in example 1.

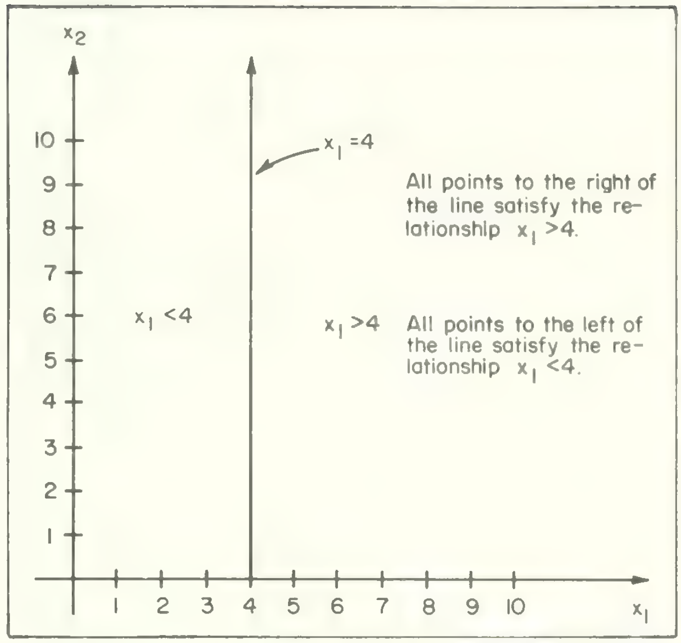

Figure 7.—A plot of the relationship $x_1 = 4$ showing the location of points where $x_1 \leq 4$ and $x_1 \geq 4$.

in the figure, all points in the first quadrant that satisfy the strict inequality $x_1 < 4$ lie to the left of the line $x_1 = 4$. Also, all points in the first quadrant that satisfy the strict inequality $x_1 > 4$ lie to the right of the line $x_1 = 4$.

We can plot the relationship $x_2 = 6$ in similar fashion (fig. 8). Note that, in this case, the points in the first quadrant below the line $x_2 = 6$ satisfy the strict inequality $x_2 < 6$ and those points in the first quadrant above the line $x_2 = 6$ satisfy the strict inequality $x_2 > 6$. The examples developed thus far can be used to compare the

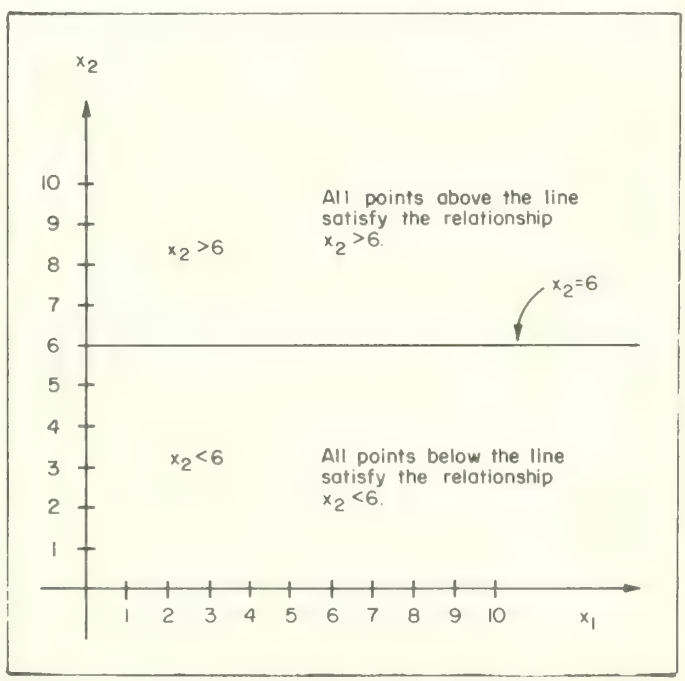

Figure 8.—A plot of the relationship $x_2 = 6$ showing the location of points where $x_2 \leq 6$ and $x_2 \geq 6$.

plotting of equalities or equations with the plotting of inequalities.

The points that satisfy any inequality can be broken down into two categories:

1. Those that satisfy the equality portion (i.e., $x_1 = 4$ or $x_2 = 6$);
2. Those that satisfy the strict inequality (i.e., $x_1 < 4$, $x_1 > 4$, $x_2 < 6$, $x_2 > 6$.

Plotting the points in the first category is equivalent to plotting linear equations in that (assuming the inequality is linear) a line will result.

The points that fall in the second category will consist of all the points below or to the left of the equality line if the strict inequality is <. On the other hand, if the strict inequality is >, then the points will be above or to the right of the equality line.

When the points satisfying an inequality are plotted, they consist of all the points satisfying the strict inequality and the points on the line that satisfy the equality.

Example 2.—We have indicated that considering only the points in the first quadrant is equivalent to considering only non-negative values for x_1 and x_2. In inequality notation, the non-negativity restrictions can be expressed as $x_1 \geq 0$ and $x_2 \geq 0$. The points satisfying the equality portions of these constraints are those lying in the positive portions of the x_1 and x_2 axes. The points satisfying the strict inequality portions are those lying in the first quadrant itself.

Example 3.—Plot the set of points satisfying the following set of inequalities:

$x_1 \geq 0$ and $x_1 \leq 4$;
$x_2 \geq 0$ and $x_2 \leq 6$.

This set of points must satisfy all four inequalities simultaneously. It is shown in figure 9 as the shaded area.

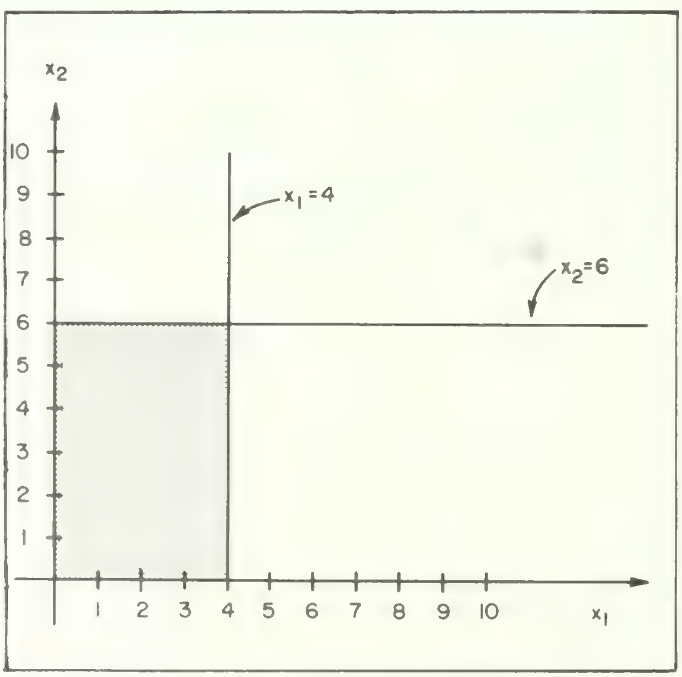

Figure 9.—The set of points satisfying $x_1 \geq 0$, $x_2 \geq 0$, $x_1 \leq 4$, and $x_2 \leq 6$.

It is particularly important in understanding linear programming that you understand the way in which sets of points satisfying inequalities are plotted. If you are having problems, study the examples and work the following exercise:

Exercise 1.—Plot the sets satisfying the following sets of inequalities:

1. $x_1 \geq 2$, $x_2 \geq 4$, $x_1 \leq 8$, $x_2 \leq 7$;
2. $x_1 \geq 5$, $x_2 \geq 6$, $x_1 \leq 15$, $x_2 \leq 9$.

LINEAR RELATIONSHIPS INVOLVING BOTH x_1 AND x_2

Until now we have considered relationships involving only x_1 or x_2. The next two subsections cover linear relationships involving both x_1 and x_2. This subsection considers equations of the form $ax_1 + bx_2 = c$, while the following subsection considers inequalities of the form $ax_1 + bx_2 \leq c$ or of the form $ax_1 + bx_2 \geq c$, where a, b, and c are specified constants.

Plotting Equations Involving Both x_1 and x_2

A relationship between x_1 and x_2 of the form $ax_1 + bx_2 = c$ is linear; a plot of the set of all points satisfying the relationship will consist of a straight line. You have probably already worked with the algebra of such linear equations. If so, perhaps you recall that once two points on any line are plotted, then the entire line can be plotted. To see how this works, consider the following relationship:

$$3x_1 + 2x_2 = 18$$

There are several methods which we may use to plot the above line.

One of the easiest is to determine the location of the intercepts, or points where the line would intersect the x_1 and x_2 axes if plotted. These points are easy to determine if one recognizes that $x_2 = 0$ where the line crosses the x_1 axis and $x_1 = 0$ where the line crosses the x_2 axis.

The intercepts can be located as follows:

1. To find where the line crosses the x_1 axis (x_1 intercept), substitute $x_2 = 0$ into the equation and solve for x_1. For our example:
$$3x_1 + 2(0) = 18$$
$$3x_1 = 18$$
$$x_1 = 6$$
and the x_1 intercept is $x_1 = 6$, $x_2 = 0$.
2. To find where the line crosses the x_2 axis (x_2 intercept), substitute $x_1 = 0$ into the equation and solve for x_2. In our example:
$$3(0) + 2x_2 = 18$$
$$2x_2 = 18$$
$$x_2 = 9$$
and the x_2 intercept is $x_1 = 0$, $x_2 = 9$.

Once this calculation is carried out, the line represented by the equation (set of points satisfying the above relationship) can be plotted simply by locating these points and connecting them with a straight line (fig. 10). Note

that, as before, we are only interested in values in the first quadrant.

You may recall seeing the equation for a line expressed in the form $x_2 = mx_1 + b$ where m is the slope and b is the x_2 intercept. Relationships in the form $ax_1 + bx_2 = c$ can be expressed in the form $x_2 = mx_1 + b$ by solving for one of the variables in terms of the other. For example, solving for x_2 in terms of x_1 in the equation $3x_1 + 2x_2 = 18$ yields $x_2 = (-3/2)\, x_1 + 9$. The slope for this example is:

$m = -3/2$ and the x_2 intercept is

$b = 9$ as shown in figure 10.

Example 4.—Plot the lines for the equations:

1. $x_1 + 6x_2 = 9$
2. $2x_1 + x_2 = 6$

For the first line, the x_1 intercept is:

$$x_1 + 6(0) = 9$$
$$x_1 = 9$$

the x_2 intercept is:

$$1(0) + 6x_2 = 9$$
$$x_2 = 3/2$$

For the second line, the x_1 intercept is:

$$2x_1 + 1(0) = 6$$
$$x_1 = 3$$

the x_2 intercept is:

$$2(0) + 1(x_2) = 6$$
$$x_2 = 6$$

These equations are plotted in figure 11.

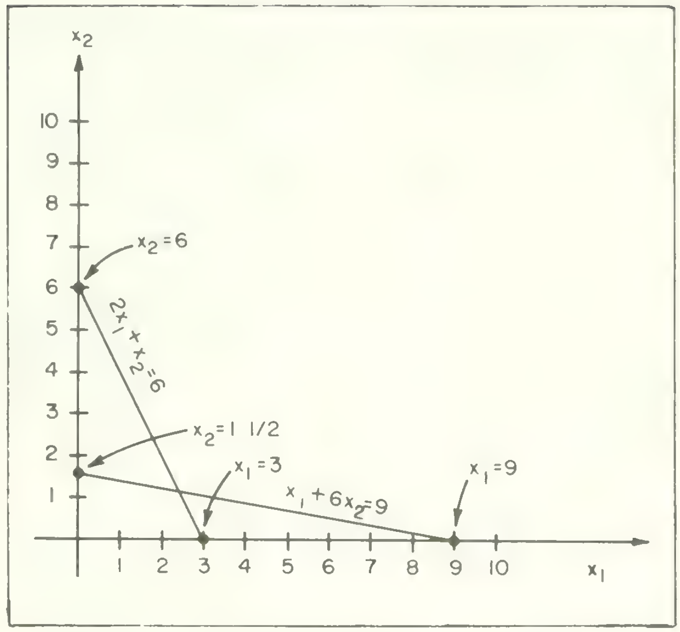

Figure 11.—A plot of the equations from example 4.

Plotting Inequalities Involving Both x_1 and x_2

The procedure for plotting points that satisfy inequalities of the forms $ax_1 + bx_2 \leq c$ and $ax_1 + bx_2 \geq c$ is basically the same as the one that was used to plot inequalities involving only x_1 or x_2. That is, we plot the line which represents the equation $ax_1 + bx_2 = c$. If the inequality is of the $\leq$ form, all points below the line in the first quadrant also satisfy the inequality. If it is of the $\geq$ form, then all points above the line in the first quadrant also satisfy the inequality.

To see this, consider the example plotted in figure 10. In this example (shown in fig. 12), all points in area A are going to yield values less than 18 when substituted into the equation.

That is, all points in A satisfy $3x_1 + 2x_2 < 18$. Consider the point P_1 denoted in the figure ($x_1 = 3$, $x_2 = 2$). Substitution of these values into the equation yields:

$$3(3) + 2(2) = 13.$$

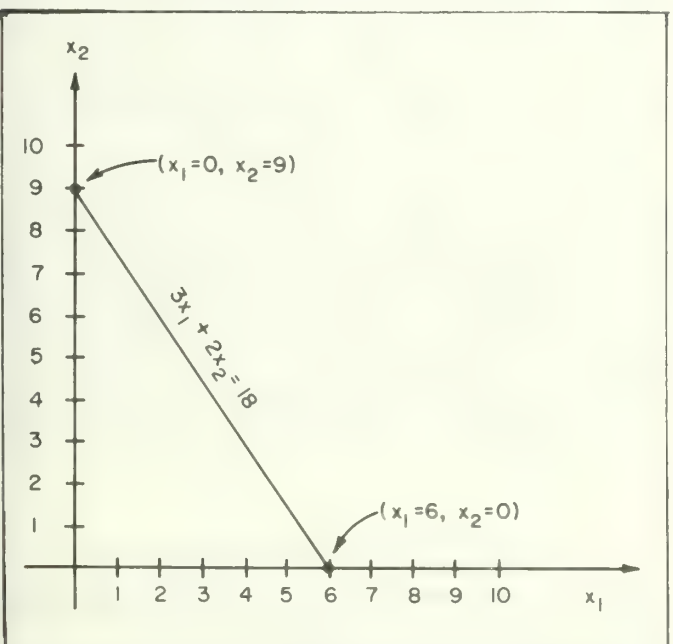

Figure 10.—A plot of the line representing the equation $3x_1 + 2x_2 = 18$.

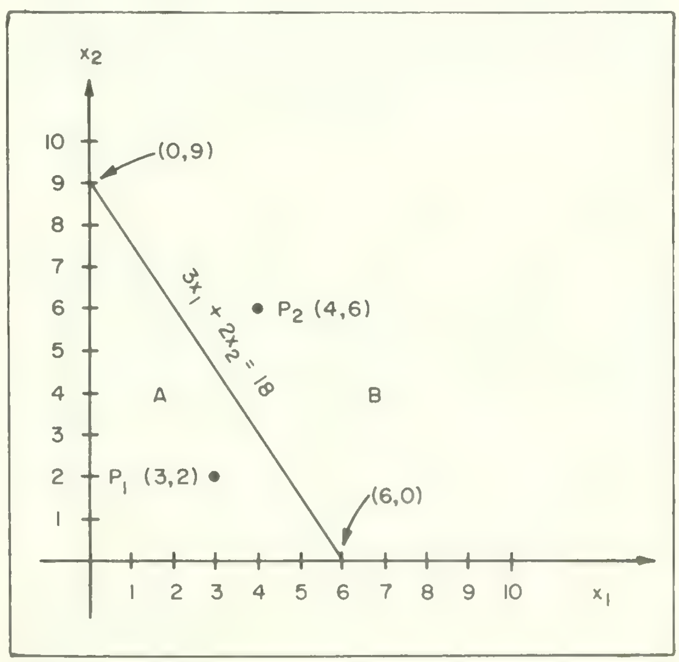

Figure 12.—A plot of a linear equation showing its relation to points that yield smaller and larger values.

Since 13 is less than 18, we have shown that the point ($x_1 = 3$, $x_2 = 2$) satisfies the strict inequality $3x_1 + 2x_2 < 18$. In the same manner, it can be demonstrated that all points in area B (above the line) satisfy the inequality $3x_1 + 2x_2 > 18$. As an example, consider the point P_2, ($x_1 = 4$, $x_2 = 6$) denoted in the figure. Substitution of these values into the equation yields:

$$3(4) + 2(6) = 24$$

Since 24 is greater than 18, the point satisfies the strict inequality $3x_1 + 2x_2 > 18$.

Using the above procedure, you should satisfy yourself that all points in area A satisfy the inequality $3x_1 + 2x_2 < 18$ and that all points in area B satisfy $3x_1 + 2x_2 > 18$. Also, all points on the line $3x_1 + 2x_2 = 18$ satisfy the equation.

Example 5.—Plot the set of points that satisfies both of the following inequalities:

$$2x_1 + x_2 \leq 6$$
$$x_1 + 6x_2 \leq 9$$

To do this, note that both inequalities are of the less than or equal to form, as points satisfying the first inequality will be below the line $2x_1 + x_2 = 6$ and all points satisfying the second inequality will be below the line $x_1 + 6x_2 = 9$ (see fig. 13). That is, the set of points satisfying the first inequality is located in areas A and B (including boundaries) in figure 13 and the set of points satisfying the second inequality is located in areas B and C (including boundaries) in the same figure. Hence, the set of points that satisfies both inequalities must be in the area denoted by B (including boundaries).

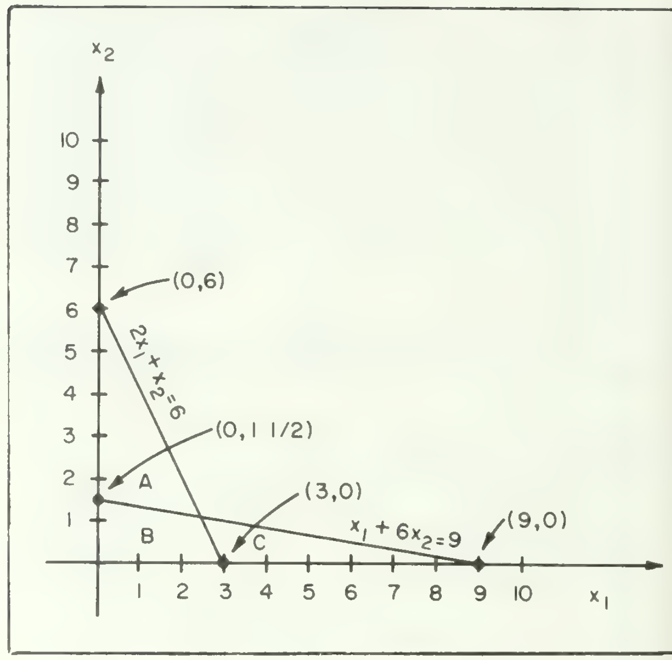

Figure 13.—A plot of the points satisfying the inequalities in example 5.

INTRODUCTION TO LINEAR PROGRAMMING

This section provides an introduction to linear programming (LP) at an elementary level. The basic concepts and terminology are presented with the aid of an extended example. Comments on notations and additional applications of LP are also mentioned.

STOCKING A RANCH EXAMPLE

Suppose that a ranch has the equivalent of 100 animal units per year (AU) of forage available for livestock. The rancher has traditionally been a cattleman, but his new wife has a love for sheep. The husband agrees to have at least 100 head of sheep if he can have at least 50 head of cattle. However, his ranch hands threaten to quit if he gets more than 200 sheep on the ranch (Keetch 1977).

The problem.—How many cattle and sheep should the rancher stock so that he will maximize profit subject to the restrictions given above?

Constraints: Additional information.—One head of cattle consumes one AU of forage per year. Five head of sheep consume one AU of forage per year. Each cow yields a profit of \$60 upon sale. Each sheep yields a profit of \$10 upon sale.

We will formulate this stocking problem as an LP problem. From the above description, it is clear that the two variables in the problem are the number of cattle and the number of sheep:

x_1 = the number of cattle;
x_2 = the number of sheep.

The problem is then to determine values for x_1 and x_2 such that the rancher's profit is maximized.

Let us develop an equation which tells us how much profit the ranch will make for any values of x_1 and x_2. Using the profit information given above, we can write:

$$\text{Profit (\$)} = 60x_1 + 10x_2$$

You should verify this relationship by checking the units of the quantities on the right hand side of the equation.

We have said that we desire to maximize profit which means that we would like to make the quantity $60x_1 + 10x_2$ as large as possible. The larger x_1 and x_2 are (the more cattle and sheep that are sold), the larger the rancher's profit will be. Such an approach is unrealistic if it ignores any "limits" or "constraints" that the capacity of the ranch places on production of cattle and sheep. In this example, the only limits specified are those arising from the capacity of the ranch for forage production and the requirements of the rancher, his wife, and his hired hands.

Constraints (Expressed Mathematically)

Now we will consider how we might express these limits or constraints in mathematical form.

Carrying capacity constraint.—There are a total of 100 AU's of forage available, which means that the livestock

can consume no more than this. From the above information, we see that:

$$\left(\frac{1\text{ AU}}{\text{head of cattle}}\right)(x_1) + \left(\frac{1/5\text{ AU}}{\text{head of sheep}}\right)(x_2) =$$

the number of AU's of forage consumed. Since we want to be sure that this does not exceed 100 AU's, we write:

$1x_1 + (1/5)x_2 \leq 100$

This inequality expresses the carrying capacity constraint mathematically. (See the Review of Elementary Graphics and Plotting section if you are not familiar with the concept of "inequalities.")

Wife's sheep requirement.—Since the wife desires at least 100 sheep, this means that:

$x_2 \geq 100$

Rancher's cattle requirement.—Since the rancher desires at least 50 cattle, this means that:

$x_1 \geq 50$

Ranch hands' sheep limitation.—Since the hands will not tolerate more than 200 sheep, this means that:

$x_2 \leq 200$

Logical or non-negativity constraints.—Since a negative number of cattle or sheep makes no sense, we have the following non-negativity restrictions on x_1 and x_2:

$x_1 \geq 0,\ x_2 \geq 0$

Exercise 2.—In general, for any LP problem, the above logical restrictions hold. In this example, however, they are redundant or not necessary. Why? Now let us write down the complete ranch stocking problem in LP format.

We want to maximize profit $(60x_1 + 10x_2)$ subject to the following constraints:

Carrying capacity, $x_1 + 1/5x_2 \leq 100$;
Wife's sheep, $x_2 \geq 100$;
Rancher's cattle, $x_1 \geq 50$;
Ranch hands' sheep, $x_2 \leq 200$
Non-negativity, $x_1 \geq 0,\ x_2 \geq 0$.

A *solution of* this problem would consist of the determination of values of x_1 and x_2 (the numbers of cattle and sheep) that will satisfy all of the constraints and that will maximize profit. That is, we want to determine values for x_1 and x_2 yielding a profit equal to or greater than the profit value arising from the selection of any other values for x_1 and x_2 that satisfy all the constraints. This solution is referred to as the optimal solution to the problem because our criterion for optimality is the maximization of the rancher's profit.

GENERAL REMARKS ABOUT LINEAR PROGRAMMING

Linear programming was first used during World War II; since then, it has been applied to a wide variety of problems. One of the most common definitions of LP is that it allocates scarce or limited resources among competing activities in an optimal manner. This definition characterizes the nature of problems to which the technique has been applied.

Exercise 3.—For the "stocking a ranch" example, identify the:

1. scarce resources;
2. competing activities; and
3. criterion of optimality.

Application areas of LP have included production scheduling, airplane fuel allocation, stock portfolio selection, shipping patterns, and warehouse storage patterns. In forestry, the technique has been applied to problems of timber harvest scheduling, sawmill operation, wood procurement, inventory planning, and land use planning.

Notation for variables.—A remark on the notation (x_1 and x_2) for the variables denoting numbers of cattle and sheep is in order. You might feel more comfortable with something like:

c = number of cattle
s = number of sheep

because it is easier to associate these variable names with cattle and sheep. If you choose to do this, there is no theoretical problem; the variables may be denoted by any name you desire. The x_1, x_2 notation is used in this report not only because this is the standard LP notation but also because "real world" LP problems often involve hundreds or thousands of variables. A systematic naming system is required in order to keep track of the variables.

THE GENERAL LINEAR PROGRAMMING MODEL

In this section, we will formulate the general linear programming (LP) model. Components of this model will be discussed and additional LP terminology introduced. When appropriate, the "Stocking a Ranch" example developed in the previous section will be used.

To describe the general model, we will use standard LP notation.

THE RANCH MODEL

The LP model for the ranch problem is a special case of the general linear programming model in that they both contain all of the same components. Components of the ranch model are reiterated here (fig. 14) to provide analogy and clarification to the discussion about the General Linear Programming Model which follows.

The general model contains n activity or decision variables and m operational constraints (not including non-negativity constraints). If we denote the decision variables by:

$x_1, x_2, \ldots, x_n$

then it is desired to find values for these variables that will maximize

$$Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$$

Maximize Profit (Z) = $60x_1 + 10x_2$		
(Objective Function)		
Subject to	$x_1 + 1/5x_2$	≤ 100
	x_2	≥ 100
	x_1	≥ 50
The following Operational Constraints	x_2	≤ 200
		$x_1 \geq 0,\ x_2 \geq 0$

Figure 14.—Components of the "stocking a ranch" model.

This set of values must satisfy both the m operational constraints:

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1;$$
$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2;$$
$$\vdots$$
$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_m;$$

and the n non-negativity constraints:

$$x_1 \geq 0,\ x_2 \geq 0,\ \dots,\ x_n \geq 0$$

The notation used for the general model is as follows.

The c_j's ($j = 1, 2, \dots, n$) are the coefficients of the decision variables (x_j) in the objective function (e.g., $3x_2$). The index j is the counting index or index of summation for the decision variables ($j = 1$ means x_1, etc.).

The b_i's ($i = 1, 2, \dots, m$) are the right hand side values (RHS) of the constraints. The index i is the counting index for the constraints ($i = 1$ means the first constraint, etc.).

Finally, the a_{ij}'s are the coefficients of the decision variables on the left hand side (LHS) of the constraints (a_{ij} is the coefficient of x_j in constraint i; $i = 1, 2, \dots, m$; $j = 1, 2, \dots, n$).

It should be noted that an important, often violated assumption of LP is that all of the coefficients in the model are known constants. This assumption will be discussed in more detail in the Advantages and Disadvantages of Linear Programming section.

A remark about the type of inequalities or operational constraints in the general model is in order. You will note that in the general model, all of the operational constraint inequalities are of the less than or equal to ($\leq$) form while the ranch problem model has two operational constraints of the greater than or equal to ($\geq$) form. The general model is given in what is known as *standard* or *canonical form*, whereas the ranch model is not in this form because of the $\geq$ constraints. Such deviations from standard form are common and, as will be seen later, they do not have a significant effect on problem solution.

Other frequently encountered situations are objective functions that are minimized and constraints in the form of equalities (=).

Now let us discuss each of the components of the LP model.

OBJECTIVE FUNCTION—QUANTIFIES THE CRITERION OF OPTIMALITY

$$(Z) = 60x_1 + 10x_2;\ \text{or}$$
$$(Z) = c_1x_1 + c_2x_2 + \dots + c_nx_n$$

This function is sometimes called the criterion function, and the associated variable Z is the criterion variable. This function serves to quantify the criterion of optimality for a given problem. It does this by assigning a numerical value (in the ranch problem, a profit value) to each solution or possible set of values on the decision variables.

In the ranch problem, the criterion of optimality is the maximization of profit, and the objective function determines the profit resulting from any values of x_1 and x_2.

In the general model, the coefficients $c_1, c_2, \dots, c_n$ measure the contribution per unit of each decision variable to the optimality criterion.

For example, in the ranch problem, c_1 = \$60 and c_2 = \$10 represent the profit per head of cattle and sheep, respectively.

We have expressed the objective function in terms of all of the decision variables in the general model, but in many problems, some of these variables may not appear in this function (see the discussion of goal programming in the Advantages and Disadvantages of Linear Programming section). This is analogous to stating that some of the c_j's may be zero.

While profit maximization is one of the most frequently used criteria of optimality, it is not the only one encountered. For example, objective functions for land use planning problems are often stated in terms of cost minimization, maximization of present net return, or maximization of the production of some product such as water, forage, or timber.

CONSTRAINTS

The constraints in the LP model have been broken into two types, operational constraints and non-negativity constraints.

Operational constraints arise from the nature of the system the model represents. For example, in the ranch problem, the first operational constraint reflects the capability of the system to produce forage. It is included in the problem because the ranch has a limit on the amount of forage it can produce, and we want to limit the production of cattle and sheep accordingly. The remaining operational constraints in the ranch problem reflect the desires of the people associated with the ranch. Further examples of the variety of forms operational constraints can take will be described later.

The non-negativity constraints are logical constraints reflecting the impossibility of having negative quantities of the commodities that the decision variables represent. For example, in the ranch problem, these constraints reflect the impossibility of having negative numbers of cattle and sheep. If you worked exercise 3, you realized that the second and third operational constraints in the ranch problem make the non-negativity constraints

redundant or unnecessary. This is not unusual, for in many problems, operational constraints make the non-negativity constraints for some of the variables redundant. Most computer LP packages automatically assume that they are part of the problem. As a result, the user does not need to specify them as data to be input into the computer.

In the general model, the a_{ij}'s ($i = 1, 2, ..., m$; $j = 1, 2, ..., n$) were used to denote the coefficients of the decision variables on the left hand side (LHS) of the constraints. As we have seen in the ranch example, $i = 1, 2, 3, 4$, (4 operational constraints) and $j = 1, 2$ (2 decision variables).

Referring to figure 14, we see that for the first operational constraint ($i = 1$), we have $a_{11} = 1$ and $a_{12} = 1/5$. Similarly, for the second operational constraint ($i = 2$), $a_{21} = 0$ and $a_{22} = 1$. Note that some of the a_{ij}'s can be zero. In most land management planning problems, the majority of the a_{ij}'s are zeros.

In the general model, the b_i's ($i = 1, 2, ..., m$) were used to denote the RHS values for the operational constraints. In the ranch example, $b_1 = 100$, $b_2 = 100$, $b_3 = 50$, and $b_4 = 200$. Each operational constraint corresponds to a limitation on some resource and the right hand side (RHS) values represent the limiting amount of these resources. In the ranch problem, forage is a limited resource; there are at most 100 AU's (the RHS of the forage constraint) available.

DECISION (ACTIVITY) VARIABLES

In any LP problem, the constraints and the objective function are linear functions of a set of variables referred to as decision or activity variables. Specifying values for decision variables is equivalent to specifying a management strategy in terms of the levels and types of activities that will be implemented. In the ranch problem, the decision variables represent the number of cows (x_1) and the number of sheep (x_2) to be stocked on the ranch. An example of a management strategy would be to stock 50 head of cattle ($x_1 = 50$) and 100 head of sheep ($x_2 = 100$). In general, for any LP problem, a strategy is specified when a non-negative value (some of these values may be zero) is assigned to every decision variable in the problem.

Linear programming derives its name from the fact that all mathematical relationships, as expressed by the objective function and constraints, are linear. That is, they contain no terms involving either powers of the x's other than one, or cross products of the x's. For example, the expressions:

$$x_1 + (1/5)\, x_2^2 \text{ and } x_1^2 + (1/5)\, x_1 x_2$$

are nonlinear in x_1 and x_2. On the other hand, all relationships in the general LP model and in the ranch problem are linear in the decision variables.

DEFINITIONS

We defined a *strategy* for any LP problem as a set of values assigned to the decision variables associated with the problem. The constraints associated with the problem define what is called the *set of feasible strategies*.

A *feasible strategy* is one that satisfies all of the constraints in the problem. The set of feasible strategies is simply the set of all that satisfy all the restraints. Since the objective function quantifies the optimality criterion for an LP problem, it determines which of the feasible strategies is the optimal strategy.

The *optimal strategy* for an LP problem is the feasible strategy that maximizes (or minimizes) the objective function. When the values of the x's corresponding to the optimal strategy are substituted into the objective function, the resultant value of Z is at least as large as (or at least as small as) the value of Z which results when the x values corresponding to any other feasible strategy are substituted.

A linear programming problem is solved by determining which strategy in the set of feasible strategies is optimal. That is, the strategy that either maximizes or minimizes the objective function is determined. A general discussion of how this is done is presented in the Land Use Problem and Some Elementary Sensitivity Analysis section of this report.

Example 6.—With reference to the ranch example, are the following strategies feasible or non-feasible?

1. $x_1 = 60$ cattle, $x_2 = 150$ sheep
2. $x_1 = 75$ cattle, $x_2 = 90$ sheep
3. $x_1 = 45$ cattle, $x_2 = 175$ sheep

1. This is a feasible solution since 60 cattle exceed the rancher's minimum of 50, and the 150 sheep lie between the wife's lower limit of 100 sheep and the ranch hands' upper limit of 200 sheep. Also, $1(60) + 1/5(150) = 60 + 30 = 90$, which is less than the upper limit of forage of 100 AU's.

2. This solution is infeasible because 90 sheep is less than the wife's minimum requirement of 100 sheep.

3. This solution is infeasible because 45 cattle is less than the rancher's minimum requirement of 50 cattle.

Note that once a strategy violates one constraint, it is not necessary to examine it further to determine infeasibility because a feasible strategy must satisfy all the constraints.

MORE LINEAR PROGRAMMING TERMINOLOGY—MATRIX AND VECTOR

The notation used above for the general LP model is standard for most disciplines that utilize the technique, and as a result, some additional terminology has been developed. To introduce this terminology, we need the following definitions:

A *matrix* is a rectangular array of numbers having a certain number of rows (m) and columns (n) where m and n are arbitrary integers.

A *vector* is a matrix composed of only one row (row vector) or one column (column vector) of numbers or variables.

Example 7.

1. $\begin{bmatrix} 2 & 1 & -1 & 0 \\ 0 & 0 & 3 & 9 \\ 4 & 16 & 0 & 7 \end{bmatrix}$ This is an m = 3 row and n = 4 column matrix (3 x 4)

2. [1 6 1 2 9] This is a 5-element row vector (1 x 5)

3. $\begin{bmatrix} 1 \\ -1 \\ -1 \\ 2 \\ 0 \\ 0 \\ 6 \end{bmatrix}$ This is a 7-element column vector (7 x 1)

In all three examples, the numbers in parentheses represent the number of rows and columns and are called the dimensions of the matrix or vector.

The terms "matrix" and "vector" are introduced here because they are frequently encountered in discussions of LP. In particular, consider the following four cases.

Case 1.—The Vector of Objective Function Coefficients

This vector (in row form) is $[c_1, c_2, ..., c_n]$ for the general LP model and is a 1 x n vector (one coefficient in the objective function for each of the n activity variables). This vector is sometimes called the cost vector or price vector.

Example 8.—In the ranch problem, the price vector is [60, 10] and is a 1 x 2 vector.

Case 2.—The Vector of Decision Variables

This vector (in row form) is $[x_1, x_2, ..., x_n]$ for the general LP model and is a 1 x n vector.

Example 9.—In the ranch problem, the vector of decision variables is $[x_1, x_2]$ and is a 1 x 2 vector.

Case 3.—The Matrix of Coefficients of Activity Variables on the Left Hand Sides of the Constraints

In the general LP model, this will be an m row (m constraints) by n column (n activity variables) matrix. That is:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot \\ \cdot \\ \cdot \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

The subscripts on the elements (a's) in the matrix identify the row and column address for each element. This matrix is called the A matrix, the activity matrix, or the technological matrix.

Example 10.—In the ranch problem (fig. 14), the A matrix is:

$$A = \begin{bmatrix} 1 & 1/5 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Note that this matrix has four rows (one for each of the four operational constraints) and two columns (one for each of the two activity variables).

Case 4.—The Vector of Right Hand Sides for the Constraints

In the general LP model, this vector (in column form) will consist of m elements (one for each operational constraint). That is:

$$B = \begin{bmatrix} b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ b_m \end{bmatrix}$$

This vector is called the resource availability vector, the requirement vector, the RHS vector, or most often, the B vector.

Example 11.—In the ranch problem, the B vector is:

$$B = \begin{bmatrix} 100 \\ 100 \\ 50 \\ 200 \end{bmatrix}$$

Note that this vector has four elements, one for each operational constraint in the problem.

If you have had any exposure to LP, you have probably heard people talking about "the matrix" or "the A matrix," and "the B vector" or "the RHS vector." This terminology arises from the LP notation just described.

THE MATRIX APPROACH TO EXPRESSING THE LP MODEL

Up to now, we have expressed linear programming models in their equation or inequality form. There is another way of writing a linear programming problem which is called the matrix or tableau approach.

To see how this is done, consider the ranch problem. This problem is displayed in matrix form in figure 15. Note that in this form, the constraints and decision variables are identified as rows and columns, respectively. The tableau or matrix contains only the coefficients of the decision variables, the constraint types, and the right hand side values. The main difference between the two formats is that, in the matrix approach, one does not write down the decision variables associated with each of the coefficients. For a small problem like the ranch

Rows (constraint types) \ Columns (decision variables)	Number of Cattle (x_1)	Number of Sheep (x_2)	Constraint Type	RHS
Forage Availability	1	1/5	≤	100
Wife's Sheep Requirement		1	≥	100
Rancher's Cattle Requirement	1		≥	50
Ranch Hand's Sheep Requirement		1	≤	200
Objective Function	60	10	–	–

Figure 15.—A matrix or tableau representation of the ranch problem.

Rows (constraint types) \ Columns (decision variables)	Number of Cattle (x_1)	Number of Sheep (x_2)	Constraint Type	RHS
Forage Availability	1	1/4	≤	100
Wife's Sheep Requirement		1	≥	100
Rancher's Cattle Requirement	1		≥	50
Ranch Hand's Sheep Requirement		1	≤	200
Rancher's Profit Requirement	60	10	≥	2000
Objective Function	60	10	–	–

Figure 16.—A matrix or tableau representation of the modified ranch problem.

problem, it takes no more time to write down the problem in equation form than in matrix form. However, for large problems involving hundreds or thousands of matrix entries, the extra time required to write down the appropriate activity variable with each coefficient is considerable. Thus, the matrix form offers time-saving advantages.

In figure 15, note that where a decision variable did not appear in a particular constraint row, instead of entering a zero, the cell was left blank. The A matrix for a typical land management problem will have a great many such empty cells because many constraint rows involve only a small number of the decision variables defined for the problem (i.e., as mentioned before, many of the a_{ij}'s = 0). Leaving the large number of cells that contain zero coefficients blank saves time and enhances the ease with which the matrix can be interpreted.

One result of the use of the matrix format has been the increasing use of the term "row" to mean constraint, and the term "column" to mean decision variable. It is important to realize that when you hear a statement like "the coefficient for sheep in the forage row is 1/5," it means that the coefficient of the decision variable representing number of sheep (in this example x_2) in the forage constraint (in this example, row 1 in the matrix) is 1/5 (fig. 15).

It is also important to realize that the numbers in a linear programming matrix really represent the coefficients of the decision variables in inequality or equality constraints. Thus, when you change these coefficients or add new ones, you are either making changes in existing constraints or are adding new constraints to the problem.

Example 12.—Consider the ranch problem again. Suppose that the rancher has received the latest extension research bulletin which contains an article that suggests that sheep consume 1/4 of a cattle AU of forage per year. Also, the rancher has determined that if he cannot make at least $2,000 per year, he would be better off selling his ranch. How do we reformulate the ranch example to account for this new information?

1. For the change in sheep forage consumption rate, all we need to do is change the entry (1/5) in the forage row for sheep to 1/4. The new forage constraint is $x_1 + (1/4)x_2 \leq 100$.
2. The profit restriction must be incorporated into the model through the addition of a new constraint which will be the equivalent of adding a new row to the matrix. This new constraint, expressed in inequality form, is:
$$60x_1 + 10x_2 \geq 2{,}000.$$

The matrix representation of this modified ranch problem is presented in figure 16. The changed coefficient and the added constraint have been circled.

THE PROBLEM OF UNITS

Until this point, we have talked about the constraint equations and inequalities without concern for the units that are associated with them. You have undoubtedly considered the problem of units for equations. Suppose we have an equation of the form A = B. For the equality to make any sense (i.e., to avoid the problem of equating apples and oranges), the quantity A must be in the same units as quantity B.

This idea carries over to inequalities in the same way. That is, an inequality like $A \leq B$ or $A \geq B$ makes no sense unless the quantities A and B are in the same units. To explore this further, let us examine the units of some of the constraints in the ranch problem. Consider the forage constraint:
$$x_1 + (1/5)x_2 \leq 100$$
The units that are implied in this relationship are:
$$\left(\frac{1 \text{ AU}}{\cancel{\text{head of cattle}}}\right)\left(x_1 \cancel{\text{ head of cattle}}\right)$$
$$+\left(\frac{1/5 \text{ AU}}{\cancel{\text{head of sheep}}}\right)\left(x_2 \cancel{\text{ head of sheep}}\right)$$
$$\leq 100 \text{ AU}$$

Note that the units "head of cattle" and "head of sheep" cancel out so that the quantity of $x_1 + (1/5)x_2$ is expressed in terms of AU's. Thus, we have the same units on each side of the inequality sign.

As another example, consider the constraint representing the rancher's cattle requirement:

$x_1 \geq 50$

In this case, the units of x_1 are cattle and the RHS of 50 also represents cattle so that the two quantities are already in the same units. The units that are implied in this relationship are:

$$\left(\frac{1 \text{ head/cattle}}{\cancel{\text{head/cattle}}}\right)\left(x_1 \; \cancel{\text{head/cattle}}\right)$$

≥ 50 head/cattle

Again, the units are the same on each side of the inequality sign.

Exercise 4.—Consider the modified ranch problem represented above. Analyze the constraints representing:

1. the wife's sheep requirement;
2. the ranch hands' sheep requirement; and
3. the rancher's profit requirement;

and verify that the quantities on each side of the inequality signs have the same units.

As a final note on units, recall the matrix representation of an LP problem described previously. As we pointed out earlier, each row in the matrix corresponds to a constraint, and each column corresponds to an activity variable. From the above discussion on units, we conclude:

1. Each activity variable (column) has an associated unit;
2. Each constraint coefficient has an associated unit; and
3. Each constraint (row) is expressed in terms of some unit that depends on the units in 1 and 2.

In developing the matrix for any linear programming problem, it is important to always keep the units in mind. We will talk more about this later as we investigate other examples.

A GRAPHICAL INTERPRETATION OF THE "STOCKING A RANCH" PROBLEM

We have been talking about the "stocking a ranch" example long enough now that it probably seems as though we are flogging a dead horse. There remains, however, one important aspect that we have not covered, and that is a graphical interpretation of the problem. Before we begin, a short discussion of the importance of this material is in order.

For small linear programming (LP) problems, like the ranch problem, involving two decision variables, we can use a simple coordinate system to graphically describe exactly what is happening in the problem. This effort serves at least two useful purposes:

1. We can plot the constraint inequalities and, hence, plot the set of feasible solutions.
2. We can gain some insight into the procedure by which an LP problem is solved.

The graphical approach is generally limited in application to two-variable problems. It is difficult (but possible) to plot in three dimensions (three decision variables), and it is impossible to plot in four or more dimensions (four or more decision variables). Despite this limitation, graphical interpretation is still a useful technique because the insights into LP that it provides for two-variable problems are equally applicable to larger problems. That is, the mathematical relationships encountered in a simple two-variable problem generalize to problems with any number of decision variables. Consider the ranch example. (If you are not comfortable with the concept of plotting equalities and inequalities, you should review the material presented in the Review of Elementary Graphics and Plotting section of this report.)

We have already indicated that any solution to or strategy for the ranch problem consists of the assignment of numerical values to the decision variables (x_1 = number of cattle and x_2 = number of sheep). Thus, we can use an x_1, x_2 coordinate system (see fig. 2) to represent all strategies or combinations of values for x_1 and x_2.

As mentioned in previous sections, in most situations, the decision variables for an LP program can take on only positive values. Certainly this is true for the ranch example, since negative numbers of cattle and sheep have no meaning. Mathematically, these logical restrictions are represented by the non-negativity constraints described in the Introduction to Linear Programming section. That is, $x_1 \geq 0$ and $x_2 \geq 0$.

From a plotting standpoint, these non-negativity restrictions enable us to ignore all quadrants of the coordinate system in figure 2 except the first. That is, the non-negativity constraints will eliminate strategies that do not correspond to points in the first quadrant.

For purposes of reference, the complete, unmodified ranch problem model is as follows:

$$\begin{aligned}
\text{Max profit } (Z) &= 60x_1 + 10x_2 \\
\text{Subject to: } & x_1 + (1/5)x_2 \leq 100 \\
& x_2 \geq 100 \\
& x_1 \geq 50 \\
& x_2 \leq 200 \\
& x_1 \geq 0,\ x_2 \geq 0.
\end{aligned}$$

As with the non-negativity constraints, the operational constraints have a graphical interpretation. Recall that in the Introduction to Linear Programming section, we indicated the following:

1. The operational constraints define a set of feasible strategies where a feasible strategy is defined to be one that satisfies all of the constraints simultaneously.
2. The optimal strategy is the strategy in the set of feasible strategies that maximizes profit (in this example) as expressed by the objective function.

We are going to divide the discussion of the graphical interpretation of the ranch problem into two parts corresponding to the two concepts listed above.

DETERMINING THE SET OF FEASIBLE SOLUTIONS

Our procedure consists of plotting each operational constraint in the ranch problem. Once all of the constraints are plotted, we can delineate the set of feasible solutions for the problem.

Wife's Sheep Constraint

To begin, consider the wife's sheep requirement constraint, $x_2 \geq 100$. The set of points (strategies) that satisfy this constraint is plotted in figure 17. This set is represented by the shaded area in the figure, which consists of all points in the first quadrant with an x_2 coordinate of 100 or more. All of the points below the line $x_2 = 100$ are eliminated from consideration as feasible solutions because they violate the wife's sheep requirement. All of the points above $x_2 = 100$ are feasible solutions as far as the wife is concerned.

Ranch Hands' Constraint

Now consider the impact of the ranch hands' sheep restriction, $x_2 \leq 200$. Figure 18 shows a plot of the set of points that satisfies both the ranch hands' and the wife's sheep requirements. This requirement eliminates any strategy having more than 200 sheep ($x_2 \geq 200$); hence, all the points above the $x_2 = 200$ violate this constraint and, therefore, cannot be feasible solutions. The two constraints in combination restrict possible feasible strategies to those that are represented by points in the shaded area in figure 18.

Exercise 5.—Are the points lying on the lines $x_2 = 100$ and $x_2 = 200$ feasible strategies at this point? Why or why not?

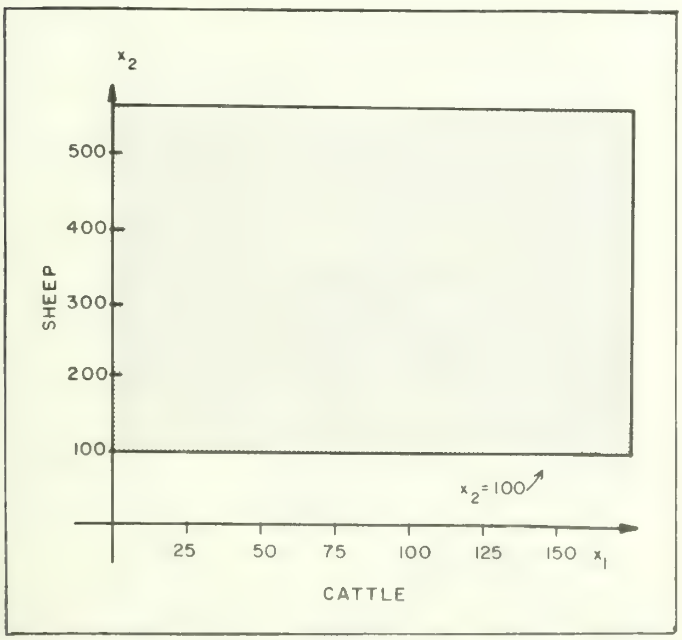

Figure 17.—The set of strategies satisfying the wife's sheep requirement.

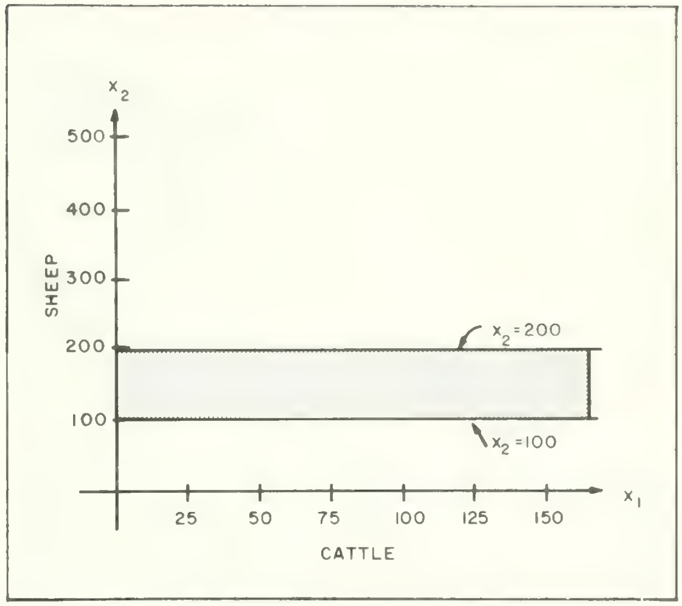

Figure 18.—The set of strategies satisfying both the wife's and the ranch hands' sheep requirement.

Ranchers' Constraint

The next constraint that we will consider represents the rancher's cattle requirement, $x_1 \geq 50$. The set of points that satisfies this requirement, and the wife's and ranch hands' requirements is represented by the shaded area in figure 19. Only points to the right of the line (as well as the line itself) represent strategies that satisfy the rancher's requirement of at least 50 cattle. The addition of the rancher's cattle requirement has had the effect of eliminating all strategies in the rectangle labeled "A" in figure 19.

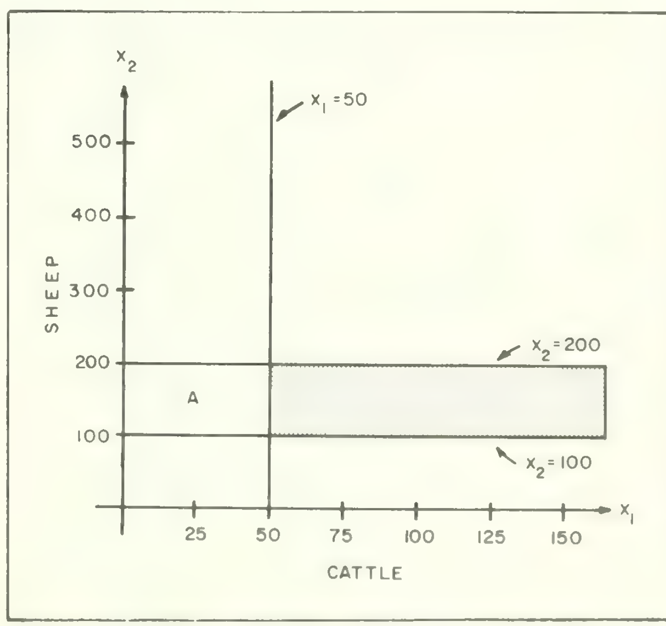

Figure 19.—The set of strategies satisfying the wife's, the rancher's, and the ranch hands' stock requirements.

Forage Constraint

Finally, let us consider the forage limitation constraint, $x_1 + (1/5)x_2 \leq 100$. This constraint is a function of both x_1 and x_2, so the plotting procedure (see the Review of Elementary Graphics and Plotting section) is different from that used for the previous constraints. Since it is a $\leq$ constraint, only strategies represented by points on or below the line $x_1 + (1/5)x_2 = 100$ will satisfy it. Hence, the only strategies that satisfy this constraint and the other three constraints are those represented by points in the shaded trapezoid in figure 20. This is the set of feasible solutions for the ranch problem.

Exercise 6.—Select two or three points in the shaded area in figure 20 and verify that they satisfy all of the constraints.

Careful study of the above plotting process can provide insight into the role of the constraints in any LP problem. Each has the effect of eliminating some strategies from consideration as feasible strategies because they violate that constraint. When all constraints are considered together, there may be a set of strategies that have not been eliminated. This set, if it exists, consists of strategies that are feasible for all of the constraints.

It is possible to have a set of constraints such that there are no strategies that satisfy all of them, and in such cases, there is no feasible strategy. This problem will be discussed in more detail in the Land Use Problem and Some Elementary Sensitivity Analysis section of this report. While we cannot represent the situation graphically, the same relationships between constraints and feasible and infeasible strategies hold for LP problems with any number of decision variables.

Exercise 7.—Verify graphically that there are no strategies (points) that satisfy all of the following constraints:

$x_1 \geq 0$
$x_2 \geq 0$
$x_2 \leq 100$
$x_2 \geq 200$

Note the similarity between these constraints and some of those in the ranch problem.

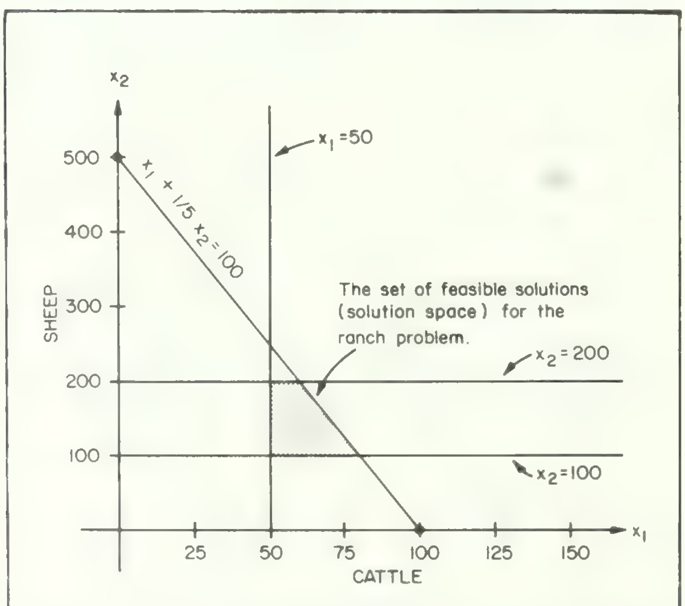

Figure 20.—The set of feasible solutions for the ranch problem.

DETERMINATION OF THE OPTIMAL SOLUTION

In this subsection, we will describe a graphical process for identification of the optimal solution for the ranch problem. This process is limited in application to problems where the set of feasible solutions can be represented graphically, i.e., for problems having only two decision variables. However, the process is useful because it shows how the nature of the objective function determines which member of the set of feasible solutions is the optimal solution. It is also useful for elaboration of some of the underlying principles of the general methodology used to solve linear programming problems.

Determining the Objective Function

We will begin the description of this process by examining the objective function $Z = 60x_1 + 10x_2$. Recall that Z is the criterion variable and, in this case, Z = profit.

We want to select the strategy contained in the set of feasible strategies in figure 20 that will maximize Z. Note that since our objective function is linear, by plotting it for different trial values of Z, we will obtain a series of parallel straight lines.

To see this, consider the following values for Z and the corresponding lines that result when the objective function is plotted.

Example 13:

$Z = 1{,}000 = 60x_1 + 10x_2$
Solve for x_2: $x_2 = 100 - 6x_1$
For this line, the x_1 intercept is: $x_2 = 0$,

$$x_1 = \frac{100}{6} = 16\ 2/3$$

The x_2 intercept is:
$x_1 = 0, x_2 = 100.$

Example 14:

$Z = 3{,}000 = 60x_1 + 10x_2$
Solve for x_2: $x_2 = 300 - 6x_1$
For this line, the x_1 intercept is: $x_2 = 0, x_1 = 50$
The x_2 intercept is:
$x_1 = 0, x_2 = 300.$

Example 15:

$Z = 6{,}000 = 60x_1 + 10x_2$
Solve for x_2: $x_2 = 600 - 6x_1$
For this line, the x_1 intercept is:
$x_2 = 0, x_1 = 100$
The x_2 intercept is:
$x_1 = 0, x_2 = 600.$

This procedure can be carried out for any value of Z, but the three we examined will suffice for our purposes. Using the techniques described in the Review of Elemen-

tary Graphics and Plotting section, the three lines are plotted in figure 21.

Note that these lines all have the same slope; all lines resulting from any choice of value for Z will have this slope. We know that for each of these lines all points on the line yield the same value for Z. For example, all points on the line $Z = 6000 = 60x_1 + 10x_2$ have coordinate values that, when substituted into the objective function, yield a profit of \$6000. In terms of strategies, this means that all strategies that yield a profit of \$6000 correspond to points on the line $6000 = 60x_1 + 10x_2$. The same remarks apply for the lines corresponding to Z = 1000, 3000, or any other value.

Now we can relate these lines to the set of feasible solutions developed earlier in figure 20. None of the three lines resulting from our selection of trial values for profit intersect this set (fig. 22). Since each of these lines corresponds to the strategies that yield profits of \$1,000, \$3,000, and \$6,000, respectively, the fact that these lines fail to intersect the set of feasible solutions suggests that all of these trial profit levels are infeasible.

Exercise 8.—Select one of the trial objective function lines plotted in figure 22 and satisfy yourself that none of the points on that line correspond to feasible solutions.

We obtained our three plots of the objective function by selecting trial profit levels or values of Z. The above discussion implies that if a profit trial value is feasible for the ranch problem, then the line that results when the objective function is plotted should intersect the set of feasible solutions (i.e., some of the points on this line correspond to feasible strategies for the problem).

Consider the lines corresponding to Z = 1,000 and Z = 3,000. These lines represent strategies that yield profits less than the smallest feasible profit.

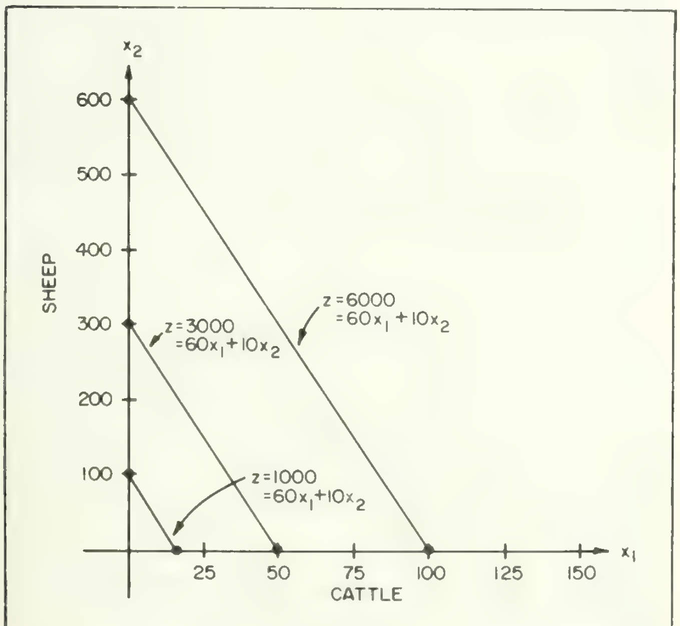

Figure 21.—Plot of the objective functions of the ranch problem for three values of profit (Z).

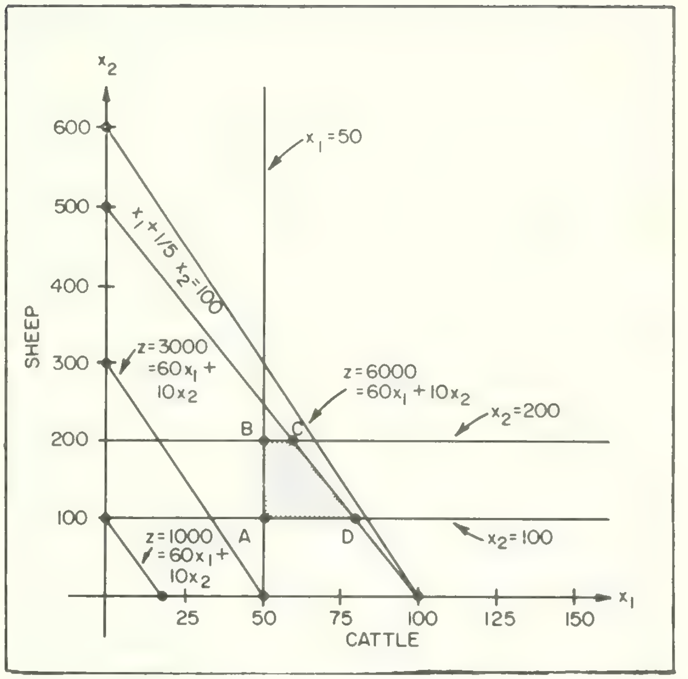

Figure 22.—Plot of the set of feasible solutions and some trial objective function values.

Consider the strategy represented by point A in figure 22. This point corresponds to the intersection of the $x_1 = 50$ and $x_2 = 100$ lines. The profit for this strategy is:

$$Z = 60(50) + 10(100) = \$4,000$$

This is a feasible strategy, and by examination of the figure, it is easy to see that any other feasible strategy will yield a greater profit.

By following the same reasoning, we can see that strategies represented by the line Z = \$6,000 yield a profit that is greater than feasible. These facts suggest that if we start with small trial values of Z and steadily increase them, the following will happen:

1. Initial profit levels defined by the trial values of Z will be less than the minimum feasible amount (4,000).
2. As trial values increase beyond 4,000, profit levels will be feasible and the lines will intersect the set of feasible solutions (fig.23).
3. At some trial value (in this case Z = \$5,800), the corresponding line will intersect the set of feasible solutions at only one point (in this case the point D). This point will correspond to the optimal strategy that maximizes profits (fig. 23).

   In general this is true, but it is possible that the line will intersect one of the boundary segments of the feasible set. Then there are an infinite number of optimal solutions. This case will be discussed in the Land Use Problem and Some Elementary Sensitivity Analysis section.
4. As larger trial values of Z (for example, Z = 6,000, fig. 22) are chosen, the line moves out beyond the set of feasible solutions. Profit levels corresponding to these lines are infeasible and greater than optimal.

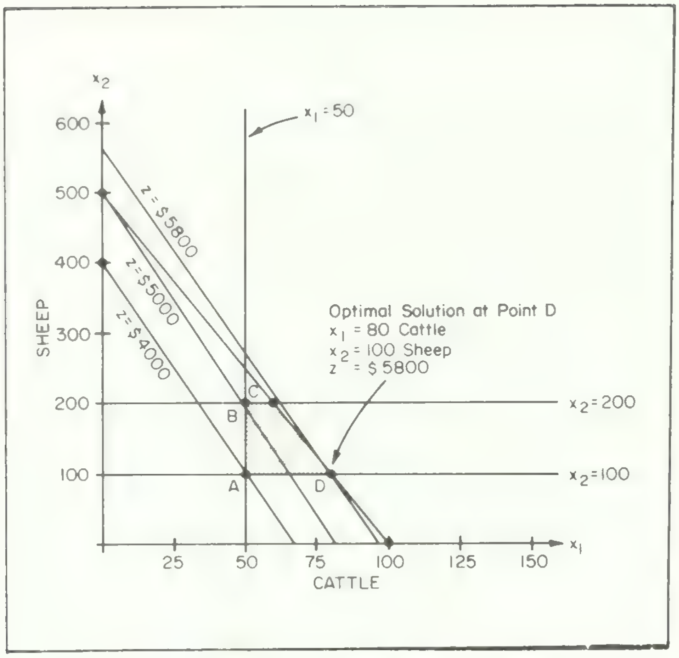

Figure 23.—The optimal solutions to the ranch problem.

THE SIMPLEX METHOD

The trial and error graphical approach to determining the optimal solution can only be applied to two-variable problems. Fortunately, the procedure used to solve LP problems is not only relatively efficient but it works for any size problem, as long as the problem is correctly formulated (see the Advantages and Disadvantages of Linear Programming section). This method is known as the simplex method, and it is an algebraic procedure rather than a graphical one.

You may have noticed that the optimal solution of the ranch problem occurred at one of the corners of the set of feasible solutions. It can be proven mathematically that for any LP problem, the optimal solution (if it exists) will be found at one of these corners. Because of this, points located at these corners take on special importance and are known by special names, the most common of which are *corner point* or *extreme point*. The strategies or solutions that correspond to these corner points are known as *basic feasible solutions*.

Exercise 9.—Determine the number and location of the corner points of the set of feasible solutions for the ranch problem.

Since the optimal solution occurs at one of the corner points, only these points need to be considered in the process of determining the optimal solution.

The simplex method is a procedure for examining selected corner points, one after the other, to determine if the corresponding solution is optimal. The procedure is mechanical or repetitive in that the same computational process is used for each corner point that is examined. The underlying algebra of the method is complex, but fortunately, it is not necessary to understand the details in order to use linear programming as a tool.

For large problems, the number of corner points is quite large. Consequently, searching them for the optimal solution in a haphazard fashion would be very time consuming, even with the aid of modern, high-speed computers. Therefore, it is important that the procedure used to conduct this search is capable of finding the optimal solution as rapidly as possible.

The simplex method meets this criterion of efficiency by selecting what might be regarded as the shortest path between the starting point and the optimal solution. That is, conceptually one can regard the simplex method as moving from corner point to corner point on a journey from a starting point around the boundary of the feasible region to the optimal solution. There are usually many possible paths. Based on previous computational experience in solving large LP's, the path chosen by the simplex method is far shorter than the longest possible path.

Since, with one exception, an understanding of the algebra of the simplex method is not required, we will not describe the procedure in this report. The interested reader is referred to any of the LP texts listed at the end of the report. We make one exception to this because the initial step in the simplex method introduces some concepts that are very important in the interpretation of the solution of an LP problem.

As we have seen, LP problems involve constraints that are often in the form of $\leq$ and/or $\geq$ inequalities. The first step in applying the simplex method to any problem involves the conversion of all these inequalities to equations or equalities.

Slack Variables

To see how this is done, consider the constraints in the ranch problem. The forage constraint is $x_1 + (1/5)x_2 \leq 100$. This constraint means that the quantity $x_1 + (1/5)x_2$, which is the amount of forage consumed by cattle and sheep, must be less than or equal to 100 AU's. Define a new variable x_3 and set x_3 equal to the difference between 100 AU's and $x_1 + (1/5)x_2$. That is, $x_3 = 100 - (x_1 + (1/5)x_2)$.

We can rewrite this equation as:

$$x_3 = 100 - x_1 - (1/5)x_2$$

or

$$x_1 + (1/5)x_2 + x_3 = 100$$

By our definition of x_3, $x_3 \geq 0$ since we cannot have negative forage. Our new variable is an example of what is called a slack variable in LP terminology. It measures the difference or "slack" between $x_1 + (1/5)x_2$ and 100 AU's of forage. If $x + (1/5)x_2$ equals 100 AU's, then $x_3 = 0$. If $x_1 + (1/5)x_2$ is less than 100 AU's, then x_3 equals the difference between the quantities.

Note that by introducing this slack variable, we have done what we set out to do (i.e., we have converted the forage inequality into an equation). We can do the same thing for any other $\leq$ type constraint.

Exercise 10.—Use the above procedure to convert the ranch hands' sheep requirement into an equation. Interpret your slack variable for this constraint.

Surplus Variables

A similar procedure is used to convert $\geq$ type constraints to equations. Consider the wife's sheep requirement constraint, $x_2 \geq 100$. This constraint states that the number of sheep (x_2) must be greater than or equal to 100. Let us define a new variable, say x_4, that represents the difference between the actual number of sheep and 100. That is, $x_4 = x_2 - 100$. This may be rewritten as $x_2 - x_4 = 100$.

By our definition of x_4, $x_4 \geq 0$ since we cannot have negative sheep. The variable x_4 is an example of what is called a surplus variable in LP terminology. This is because x_4 measures the difference or surplus between x_2 and 100 sheep. Another way to think of this is to regard all sheep in excess of 100 as extra or "surplus" sheep. For example, if $x_2 = 100$ sheep, then there are no surplus sheep and $x_4 = 0$.

Note that, as with slack variables, we have converted the inequality to an equality. This procedure can be applied to any other $\geq$ constraint.

Exercise 11.—Use the surplus variable procedure to convert the rancher's cattle restriction to an equality. Interpret your surplus variable for this constraint.

Prior to solving any LP problem with the simplex method, a slack variable is introduced to every $\leq$ constraint in the problem and a surplus variable is introduced to every $\geq$ constraint in the problem. For example, if a problem has 100 $\leq$ constraints and 78 $\geq$ constraints, there will be 100 slack variables and 78 surplus variables introduced. This is done automatically within the computer. In solving the problem, the simplex method finds values for the slack and surplus variables as well as for the original activity variables. The values of these variables provide useful information because they tell us how much of each of the resources are unused ($\leq$ constraints) or over-produced ($\geq$ constraints). For example, we saw that in the ranch problem the optimal solution was $x_1 = 80$ cattle and $x_2 = 100$ sheep (fig. 23). The amount of forage consumed is $1(80) + 1/5(100) = 100$ AU's. That is, there is no forage left and our slack variable, x_3, is equal to zero in the optimal solution. In other words, there is no excess forage and forage is a limiting resource in this problem.

Exercise 12.—Determine the optimal values of the slack and surplus variables for the other three constraints in the ranch problem. Interpret the meaning of these values.

A LAND USE PROBLEM AND SOME ELEMENTARY SENSITIVITY ANALYSIS

The three previous sections of this report have been devoted to an in-depth analysis of the ranch problem. Some linear programming (LP) terminology has been introduced and basic solution concepts have been discussed. This section will be devoted to the formulation of a simple land management problem as an LP problem. Certain aspects of the role of LP in the planning process and some complications that may arise in problem formulation will be discussed. Exercises are presented at the end of the section.

A SIMPLE ALLOCATION PROBLEM: WILSON'S TIMBER-RECREATION MODEL[3]

Consider a 100,000-acre tract of national forest land located in an isolated unit. We are trying to decide how many acres to devote to timber production and how many acres to devote to concentrated recreation (campgrounds and picnic areas). That is, we are considering two management prescriptions that will correspond to the following decision variables:

- x_1 – # of acres subjected to timber-intensive management.
- x_2 – # of acres subjected to recreation-intensive management.

We know that the area will produce 400 board feet of timber per acre per year, on the average. No concentrated recreation developments are possible in the areas devoted to timber-intensive management because clearcutting is the timber harvest method practiced (resulting in timber emphasis areas being completely denuded at the end of each rotation). Also, the areas are subjected to periodic commercial thinnings during the rotation. In the winter, some timber can be harvested from the areas devoted to concentrated recreation because there is no recreational use at that time. To preserve the forest environment, this cutting must be done on a selective basis and results in an average annual timber production of only 100 board feet per acre. Established timber processing plants in the vicinity have historically used 20 million board feet per year from the area. It is arbitrarily decided that the area will continue to provide at least this amount. Additional processing capacity will be encouraged up to the amount of timber that will prove to be available after the acreage allocation is determined. Timber from the area has an average end product wholesale value of \$160 per thousand board feet. Forest Service costs for timber management practices or activities average \$10 per thousand board feet produced. Net timber value is then \$150 per thousand board feet.

Campgrounds and picnic grounds are constructed to provide three units on each acre developed, but these developed areas require rather wide buffer areas and acreage for nature trails and other features. On an average, each camp or picnic unit requires 10 acres to be devoted to recreation. Each unit receives an average of 200 visits per year (or 20 visits per acre per year). There are presently 100 units on the area receiving a total of 20,000 visits per year. These visits are valued at \$5 each for what they contribute to the economy on the basis of average end product wholesale value. Forest Service recreation management costs for the area have averaged \$1 per recreation visit, leaving a net recreation value of \$4 per visit. There is a great interest in recreation, and all areas that have been developed have soon been used to capacity. Recreation planners recommend, and it is agreed, that provision for recreation visits should be at least double the present use, and that the maximum number of visits the area can sustain without serious

[3] *Adapted from a problem presented in a Masters thesis by Carl N. Wilson, University of Montana, 1967.*

degradation of recreation quality is 400,000. A summary of the cost and net value calculation is presented in table 2.

Using the information given in table 2, we will formulate a linear programming model to represent the situation. Suppose that we desire to maximize net value or revenue. Based on the information in table 2, our objective function for this problem is:

$$\text{max net revenue} = 60x_1 + 95x_2$$
or
$$\max Z = 60x_1 + 95x_2$$

In order to meet the requirements outlined above, we will need the following constraints:

1. An acreage constraint (we cannot manage more than the 100,000 acres):
$$x_1 + x_2 \leq 100{,}000 \text{ acres.}$$
2. A timber demand constraint:
$$400x_1 + 100x_2 \geq 20{,}000{,}000 \text{ board feet.}$$
3. A minimum recreation capacity constraint:
$$20x_2 \geq 40{,}000 \text{ visits.}$$
4. A recreation carrying capacity constraint:
$$20x_2 \leq 400{,}000 \text{ visits.}$$
5. Non-negativity constraints (we cannot have a negative number of acres):
$$x_1 \geq 0,\ x_2 \geq 0.$$

In the event you are unsure of how the information given above was used to develop the objective function and constraints, you should review the material on units in the Introduction to Linear Programming section. Verify for yourself that the units are correct for this problem as given.

The complete LP model is:

max revenue
$$\max Z = 60x_1 + 95x_2$$
subject to:
$$\begin{aligned} x_1 + x_2 &\leq 100{,}000 \\ 400x_1 + 100x_2 &\geq 20{,}000{,}000 \\ 20x_2 &\geq 40{,}000 \\ 20x_2 &\leq 400{,}000 \\ x_1 \geq 0,\ x_2 &\geq 0 \end{aligned}$$

We can, using the terminology introduced in the General Linear Programming Model section, identify the following matrix and vectors for this problem:

1. The vector of objective function coefficients or price vector is:
[60, 95].
2. The vector of decision variables is:
$[x_1, x_2]$.
3. The matrix of coefficients of activity variables on the LHS of the constraints (the A matrix) is:
$$A = \begin{bmatrix} 1 & 1 \\ 400 & 100 \\ 0 & 20 \\ 0 & 20 \end{bmatrix}$$
4. The vector of constraint RHS (the B vector) is:
$$B = \begin{bmatrix} 100{,}000 \\ 20{,}000{,}000 \\ 40{,}000 \\ 400{,}000 \end{bmatrix}$$

Table 2.—Calculation of costs and net values per acre per year.

Resource emphasis	Timber	Recreation
Timber		
Volume	400	100
Net value	\$150 x .4 = \$60	\$150 x 0.1 = \$15
Recreation		
Visits	0	20
Net value	0	\$4 x 20 = \$80
Total net value	\$60	\$95
Total cost	\$ 4	\$21

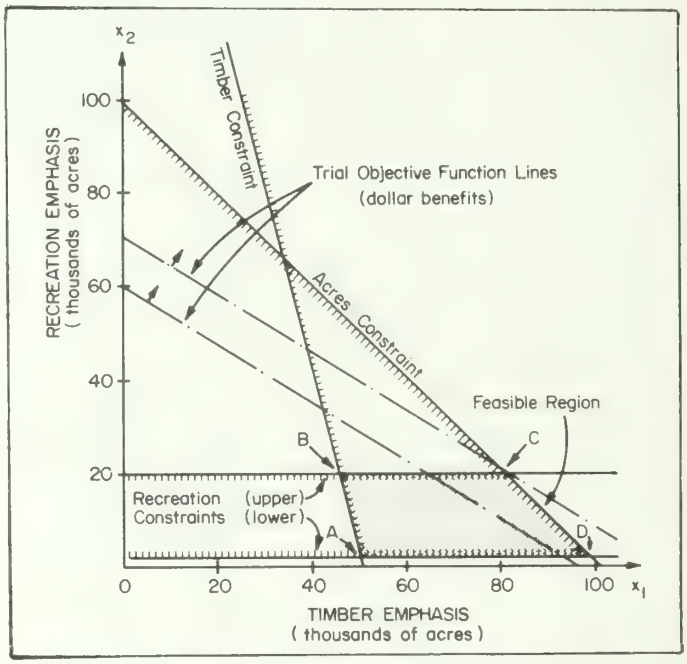

Figure 24.—Graphical representation of Wilson's TR model.

By following the steps outlined in the Graphical Interpretation of the "Stocking a Ranch" Problem section, the set of feasible solutions for the TR problem may be plotted. This plot is shown in figure 24. From the remarks we made in that section, we know the optimal solution must be located at one of the four corners or extreme points (labeled A, B, C, and D in fig. 24). Using either the graphical procedure (see fig. 24) or the simplex method, it can be shown that the optimal solution is located at point C. This solution is:

x_1 = 80,000 acres managed for timber;
x_2 = 20,000 acres managed for recreation; and
Max Z = \$6,700,000, of which \$4,800,000 comes from timber and \$1,900,000 comes from recreation. Verify for yourself that these objective function values are correct given the values of x_1 and x_2.

WILSON'S TR MODEL AND THE NFMA PLANNING PROCESS

Management Practices and Management Prescriptions

Certain components of Wilson's TR problem can be related to some of the concepts or terms that have devel-

oped within the context of the NFMA planning process. For example, consider the terms *management practice, management prescription, capability area,* and *analysis area.* A management practice is defined in the regulations as:

a specific action, measure, or treatment.

A management prescription is defined in the regulations as:

management practices selected and scheduled for application on a specific area to attain multiple use and other goals and objectives.

Management prescriptions correspond to columns or decision variables in an LP allocation model.[4] Thus, Wilson's TR problem, timber-intensive management, and recreation-intensive management are management prescriptions. Note that each is comprised of several management practices. For example, practices included in the recreation-intensive prescription include the construction of picnic grounds and campgrounds and the selection cutting of timber.

The allocation component of an LP model developed for a forest planning effort will contain decision variables that correspond to the number of acres managed under possible prescriptions that may be applied to the land within the forest. It is important to recognize that in developing management prescriptions enough detail must be specified so that production coefficients, costs, etc., can be developed, as was done in the Wilson TR example. This is necessary because these values are an important part of the LP model.

Analysis Areas

Within such a model, the land base for a national forest will be represented by a number of components called analysis areas and a set of prescriptions will be developed for each area. In Wilson's TR problem, there is only one analysis area (the 100,000 acre tract of land mentioned in the problem description) and only one set of prescriptions. Within the allocation model, the analysis area is the fundamental unit of land in that it is the land unit to which an acreage constraint is related. That is, there will be a constraint that ensures that the total acres allocated to all prescriptions possible for a given analysis area must be less than or equal to the total number of acres in the analysis area. For the single analysis area and set of two prescriptions in Wilson's TR problem, the acreage constraint is $x_1 + x_2 \leq 100{,}000$ as given in the problem description.

As mentioned above, many analysis areas would be required in an LP model for an entire national forest. At least one acreage constraint would be necessary for each of them, and in some cases, more than one might be required. To see why this might happen suppose that for some reason it is desired in Wilson's TR problem to restrict the number of acres managed by timber-intensive management (x_1) to be no more than 30,000; this can be handled within the model with another acreage constraint involving only x_1. That is:

$x_1 \leq 30{,}000$

Thus, if it is desired to restrict the number of acres a given type of management may be applied to within an analysis area, additional acreage constraints (sometimes called secondary acreage constraints) are required. The set of acreage constraints for the different analysis areas would be one component of a forest-wide LP model.

Each analysis area has the potential of being made up of a single capability area, part of a capability area, part of several capability areas, or several capability areas. Several procedures for the identification of capability areas exist depending on factors such as the nature and type of data available, the nature of the land area in question, and the types of issues, concerns, and opportunities that must be addressed.

It is possible that several thousand capability areas might be identified on a national forest. If these were to be the fundamental units of land in an LP, several thousand acreage constraints of the type just discussed would be required. Clearly, this gets into model size problems and this is one reason why it is necessary to aggregate capability areas into analysis areas.

Limitations of an LP Allocation Model

At this point, some comments are in order about the relationship between the solution of an LP allocation model and the problem of linking this solution to what is actually on the ground. A solution will provide information on how many acres should be managed with each prescription within each analysis area. For example, the solution of Wilson's TR problem tells us to allocate 80,000 acres to timber-intensive management and 20,000 acres to recreation-intensive management. The problem arises from the fact that the model does not tell us which acres of the 100,000 available to allocate to each prescription. This is a problem with any LP allocation model in that decisions will need to be made outside of the model as to which acres within each analysis area are managed by which prescription. In other words, each solution must be tested for spatial feasibility on the ground to ensure that it will be workable.

The NFMA Planning Process

While Wilson's TR model is a very simple example, the steps required for its development can be related to various actions in the NFMA planning process. For example, refer to table 1 which outlines some of the planning activities that should take place during the implementation of the actions of the process. The existence of demand for timber and concentrated recreation would be determined through various planning activities within the "Identification of Issues, Concerns, and Opportunities" action. Actual demand estimates would be developed during the "Demand Analysis" phase of the "Analysis of the Management Situation" (table 1). The data on timber and recreation management

[4] *It should be recognized that while only allocation is considered here, scheduling of prescriptions over time will also be handled through LP.*

values and costs would be developed during the "Inventory Data and Information Collection" action.

The estimates of board foot yields and current recreation use would be determined in the development of resource output coefficients during the "Analysis of the Management Situation." The timber and recreation management practices, including such things as harvest systems and sizes and capacities of picnic and campsite areas, would be dealt with during the "Management prescription development" phase of the "Analysis of the Management Situation." This development would be based on findings from the "Identification of Issues, Concerns, and Opportunities" actions and "Suitability/capability analysis" activity in the "Analysis of the Management Situation." All of this information would be incorporated into the model during the LP matrix generation activities of the "Analysis of the Management Situation."

GENERATING ALTERNATIVE PLANS BY CHANGING THE MODEL

The solution of the model yields a management plan that allocates acres to management prescriptions and produces timber and concentrated recreation. Alternative plans could be generated by making changes in the model (i.e., adding constraints, changing coefficients or the objective function, etc.) and solving the modified problems. Each solution would correspond to an alternative plan, and this would be done during both the "Analysis of the Management Situation" and the "Formulation of Alternative" actions.

Changing the Model to Perform a Sensitivity Analysis

Example 16.—With reference to Wilson's TR problem, suppose that budget is an additional concern. That is, there is a limit of $500,000 per year that may be spent on management prescriptions.

Let us modify the original problem to incorporate this new restriction. We know from the information in table 2 that it costs $4.00 per acre (400 board feet/acre x $10 cost/thousand board feet) to manage for timber. For recreation management, the cost is $21 per acre (20 units/acre x $1/visit + 100 board feet timber/acre x $10 cost/thousand board feet). Since we must spend less than the budget limit of $500,000, the budget constraint may be written:

$$4x_1 + 21x_2 \leq 500{,}000$$

The new model is developed from the original by adding this new constraint. That is:

$$\text{Max } Z = 60x_1 + 95x_2$$

subject to:

acreage constraint	$x_1 + x_2 \leq 100{,}000$
timber demand constraint	$400x_1 + 100x_2 \geq 20{,}000{,}000$
minimum recreation constraint	$20x_2 \geq 40{,}000$
maximum recreation constraint	$20x_2 \leq 400{,}000$
budget constraint	$4x_1 + 21x_2 \leq 500{,}000$
non-negativity constraints	$x_1 \geq 0,\ x_2 \geq 0$

At this point, it is reasonable to ask, "How does the addition of the budget constraint affect the problem in terms of selection of an optimal solution or management plan?"

To answer this question consider the graphical representation of the modified problem shown in figure 25. This shows that the addition of the budget constraint has reduced the size of the set of feasible solutions. To see this, compare the feasible region in figure 24 for the original problem with that in figure 25 for the modified problem. The stippled area contains all the points representing solutions that were feasible for the modified problem. Comparison of these figures shows that the optimal solution to the original problem (point C in fig. 24) is not feasible for the modified problem. To determine the new optimal solution we can use the graphical procedure as before. Doing this, we find that the new optimal solution is located at point C_1 (fig. 25). This solution is:

x_1 = 94,117.65 acres managed for timber;
x_2 = 5,882.35 acres managed for recreation; and
Max Z = $6,205,882.25, of which $5,647,059.00 comes from timber and $558,823.25 comes from recreation.

The effects of adding this budget constraint to the problem are shown in table 3.

To summarize, 14,117.65 acres were taken out of recreation production and placed in timber production in the modified problem. This resulted in a reduction of revenue of $494,117.75 because each of the 14,117.65 acres yielded $95 of revenue per acre when managed for recreation, but only $60 per acre when managed for timber, a reduction of $35 per acre.

($35)(14,117.65) = $494,117.75

This reduction was caused by the fact that we could only spend $500,000 because of our budget limitation; and in the original problem, where budget was unconstrained, we spent ($4)(80,000) + ($21)(20,000) = $740,000.

To meet the required budget reduction, acres managed for recreation in the original plan were shifted to timber management because of the lower cost.

As mentioned above, each time we modify and solve any LP planning model, we generate an alternative plan. A major purpose in doing this is to be able to analyze trade-offs between alternative plans (Analysis of the Management Situation and Formulation of Alternative actions, table 1). In the example just cited, we have a potential trade-off between budget and revenue. A reduc-

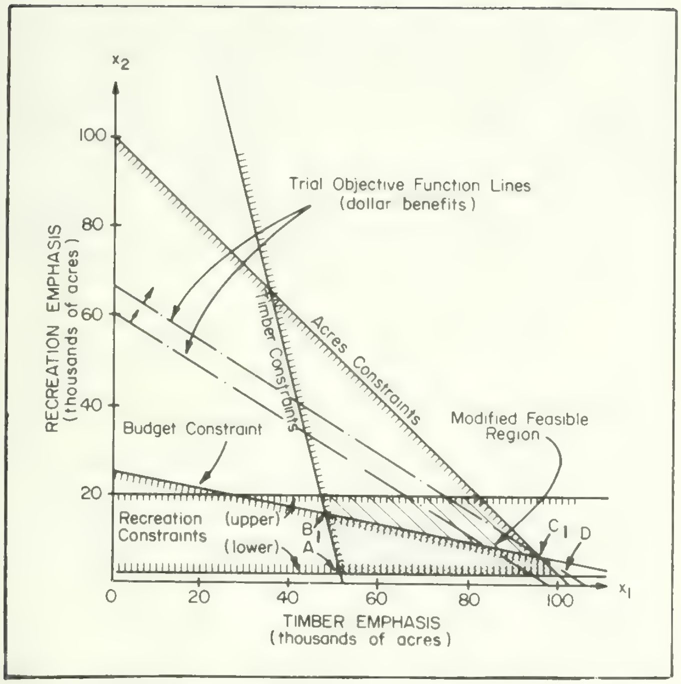

Figure 25.—Graphical representation of Wilson's TR model with budget constraint added.

tion in our budget from \$740,000 to \$500,000 leads to a reduction in revenue of \$494,117.65. Any comparison of these two plans would need to consider this trade-off. If this were a real situation, it would be necessary to determine if an increase in revenue of almost \$500,000 justifies an increased expenditure of \$240,000. In the same way, other trade-offs arising from changes in the model can be analyzed (see exercise 14).

We have just described a very simple example where we have investigated the effects of a change in the model on the optimal solution. This sort of analysis is often called a *sensitivity analysis* or *post-optimality analysis.* For a small problem like this, the effect of such a change is easy to see since we can use graphics to illustrate it. However, for a large problem, the effect of such a change can be quite subtle and a more careful analysis is needed. Most computer packages print out, in addition to the optimal solution, information that aids in sensitivity analysis.

One important type of change in an LP model that will be made in order to generate alternative plans is a change of objective functions. Within a given LP model, one can choose any row or relationship to be the objective function. For example, consider the modified Wilson TR problem developed in example 17. The objective function chosen is the maximization of net revenue. Other objective functions that could be chosen are:

1. Maximize timber production;
2. Minimize timber production;
3. Maximize recreation production;
4. Minimize recreation production;
5. Minimize budget.

It should be obvious that choosing one of these alternative objective functions will often lead to a different optimal solution than the one corresponding to the corner point C_1 (fig. 25). If we assume that all constraints are as specified in example 16, then the feasible region will be as shown in figure 25. From what we have said about the simplex method, we know that the optimal solution, regardless of our choice of objective functions must occur at one of the four corner points A, B_1, C_1, or D. Of course, each of these corresponds to different allocations of the land and, hence, different alternative plans.

Altering the Objective Function—Maximize Timber Production

Example 17.—Consider the objective function "Maximize Timber Production." That is:

$$\text{Max } Z = 400x_1 + 100x_2$$

subject to:

acreage constraint $\quad x_1 + x_2 \leq 100{,}000$

timber demand constraint $\quad 400x_1 + 100x_2 \geq 20{,}000{,}000$

minimum recreation constraint $\quad 20x_2 \geq 40{,}000$

maximum recreation constraint $\quad 20x_2 \leq 400{,}000$

budget constraint $\quad 4x_1 + 21x_2 \leq 500{,}000$

non-negativity constraints $\quad x_1 \geq 0,\ x_2 \geq 0$

In order to maximize timber production, as many acres as is feasible should be allocated to the timber intensive prescription. Since 2,000 acres must be allocated

Table 3.—Comparison of optimal solutions for two versions of Wilson's TR model

Item	Original solution	New solution	Amount of change	Direction of change
Timber (x_1) (acres)	80,000	94,117.65	14,117.65	increase
Recreation (x_2) (acres)	20,000	5,882.35	14,117.65	decrease
Revenue (Z)	\$6,700,000	\$6,205,882.35	\$494,117.65	decrease

to the recreation prescription in order to meet the minimum recreation constraint, 98,000 acres are available for timber intensive management and the optimal solution occurs at the point D, $x_1 = 98{,}000$ acres, $x_2 = 2000$ acres (fig. 25). From this, it is easy to determine the corresponding levels of outputs of the various products and services as was done in the previous examples.

Altering the Objective Function—Minimize Budget

Example 18.—Consider the objective function "Minimize Budget." That is:

$\min Z = 4x_1 + 21x_2$

subject to the same constraints as shown in example 17.

Clearly, the way to minimize budget is to minimize the number of acres managed, especially the number of acres managed under the recreation prescription since it is more costly ($21 versus $4 for the timber prescription).

The corner point A corresponds to this, and the solution is to manage the minimum of 2,000 acres under the recreation prescription and 49,500 acres under the timber prescription. Note that in this solution, 48,500 acres are not managed by either prescription. If it is required that all acres be managed in some fashion, this would be an unacceptable solution. There are at least two ways in which the problem could be modified in order to resolve this difficulty. The simplest change would involve the modification of the acreage constraint to force all of the acres to be managed. That is:

$x_1 + x_2 = 100{,}000$

Note that if this were done, the feasible region would become the line segment C_1D in figure 25 (see exercise 13). It is possible that forcing all acres to be managed under one or the other of these prescriptions may be undesirable. An additional prescription, a minimum level of management, could be defined. If the number of acres to be allocated to this prescription is denoted by x_3, then the acreage constraint would be:

$x_1 + x_2 + x_3 = 100{,}000$

If no other changes are made in the model, then the 48,500 acres not managed under the timber and recreation prescriptions would be managed under the minimum level of management in this example.

One final comment on examples 17 and 18 is in order. As presented, there is no consideration of net revenue in the model once the objective function is changed. It would be easy to rectify this by adding a revenue constraint if this were desired. For example, if it were desired to generate at least $5,000,000 in net revenue, a constraint of the form:

$60x_1 + 95x_2 \geq 5{,}000{,}000$

could be included in the model.

SOME ADDITIONAL ASPECTS OF LP PROBLEM FORMULATION

Wilson's Timber-Recreation model illustrates problems that may occur during LP problem formulation. These difficulties can be encountered (and often are) in LP problems of any size, and their characteristics are easy to demonstrate in a two-variable problem because graphical representation is possible. Some aspects of problem formulation such as an infinite number of optimal solutions and redundant constraints do not cause any difficulties in determining an optimal solution, but others such as non-feasible solutions or an unbounded optimal solution make determination of an optimal solution impossible.

Infinite Number of Optimal Solutions

Until now the LP problems considered have had a unique optimal solution. However, it is possible for an infinite number of solutions satisfying the criterion of optimality to exist; that is, each of these solutions maximize or minimize the objective function. To see how this can happen we will change the objective function for the Timber-Recreation problem by changing the coefficient of x_2 from $95 to $60. That is:

$\max \text{revenue } (Z) = 60x_1 + 60x_2$

This is, of course, equivalent to changing the net return for intensive recreation management from $95/acre to $60/acre.

If we consider the original problem (no budget constraint), then the set of feasible solutions shown in figure 26 is exactly the same as that shown in figure 24. However, when we use the graphical approach to solve the problem with the modified objective function, we note that the slope of the lines representing trial objective function values has changed because of the change in the coefficient of x_2. In fact, the slope is the same as that of the line representing the acreage constraint. As we plot lines corresponding to increasing values of revenue, we find that eventually (at revenue = $600,000) the objective function line and the acreage constraint line are one and the same.

Recall that in our previous examples, as we selected increasingly large trial values for the objective function, we eventually reached a value where the objective function line intersected only one point (a corner point or extreme point) in the set of feasible solutions. This point corresponded to the optimal solution (assuming a maximization problem) because when we picked larger values for the objective function, the corresponding lines lay completely outside the set of feasible solutions. That is, these lines correspond to values of profit or revenue that are larger than the values yielded by any feasible solution.

This holds for the example in figure 26 in that selection of any objective function value greater than $600,000 leads to a line that lies outside the feasible region. The important point to note is that this objective function line intersects the feasible region not at just one point, but rather at every point on the line segment C_1D. This means that every point on this line segment corresponds to an optimal solution because all these points yield a $600,000 return. This is easy to verify by determining the coordinates of any point on this line segment and substituting them into the objective function. For exam-

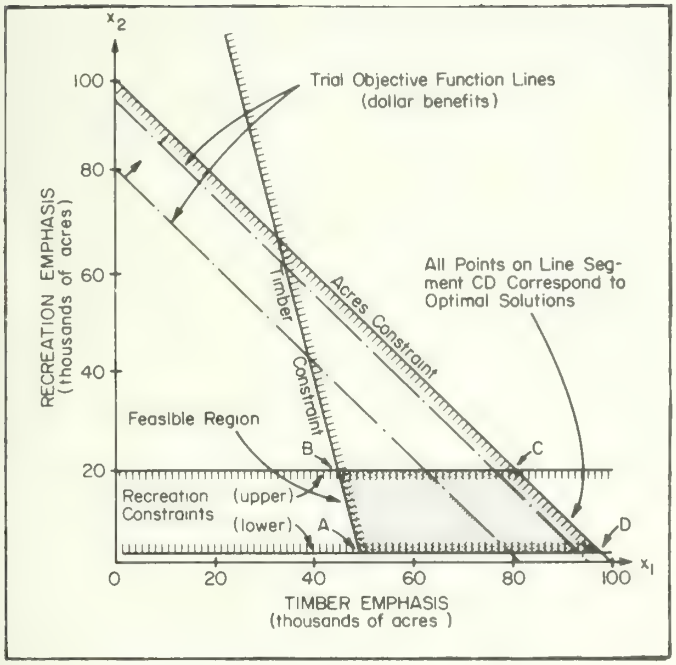

Figure 26.—Multiple optimal solutions encountered when objective function is changed to $Z = 60x_1 + 60x_2$.

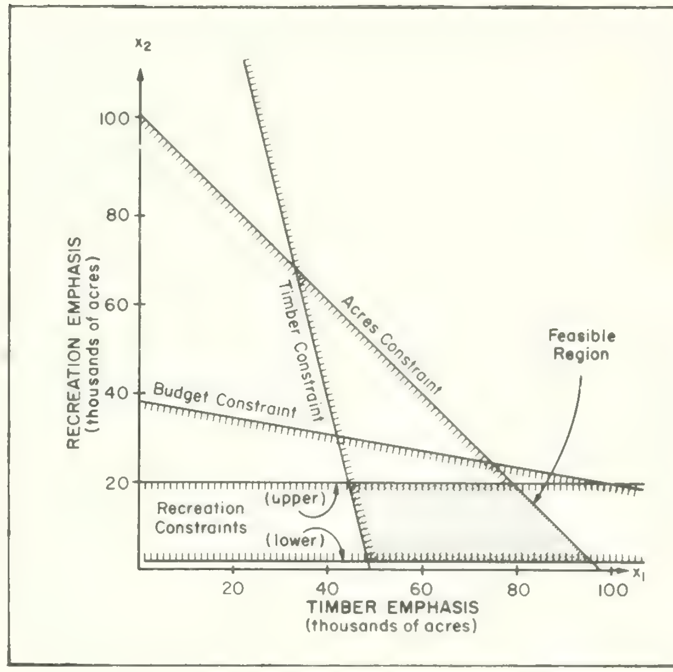

Figure 27.—Graphical representation of TR problem with budget limit of $750,000.

ple, the coordinates of the point D are $x_1 = 98{,}000$, $x_2 = 2{,}000$, and:

return = (60) (98,000) + (60)(2,000) = $600,000.

Hence, any solution (there are an infinite number of these) on this line segment is optimal and may be implemented. Note that this is caused by the fact that the slope of the objective function line is the same as the slope of one of the constraint lines (in this case the acreage constraint). While this can occur with problems of any size, it does not present any difficulties in using the simplex method to determine the optimal solution. In fact, the simplex method will detect multiple optimal solutions if they exist.

Redundant Constraints

Consider the addition of a budget constraint to the original TR model, but now assume that the budget limitation is $750,000 instead of $500,000. That is, the budget constraint is:

$4x_1 + 21x_2 \geq 750{,}000$

A graphical representation of the problem including this constraint is presented in figure 27. Note that this constraint lies outside the set of feasible solutions but that every point in the set of feasible solutions satisfies it since it is a $\leq$ constraint. Thus, it does not alter the original set of feasible solutions, and the optimal solution would be exactly the same as for the original problem. A constraint that does not alter the problem by changing the set of feasible solutions is called a redundant constraint. In large problems, redundant constraints are difficult to detect because a graphical representation of the problem cannot be developed. Most efficient computer software LP packages eliminate redundant constraints for the sake of efficiency of solution before attempting to solve the problem.

Another way to describe redundant constraints is to say they are not binding or that other constraints in the problem are more binding or more constraining. This is true here because if you will recall, we spent $740,000 to implement the optimal strategy for the original TR problem. This was the most money we could spend because of the acreage constraint; that is, we had only 100,000 acres to manage. Since we can spend at most $740,000, it is obvious that an extra $10,000 (a budget of $750,000) is not going to do us any good. In other words, the acreage limit is more binding than a budget of $750,000 because we cannot spend that much money on the available acreage given the other constraints. Of course, if some other constraint were changed, then it might be possible to exceed a $750,000 budget and, thus, make this constraint binding (see exercise 15).

No Feasible Solution

To illustrate this situation consider a budget limitation of $160,000. That is, the budget constraint is:

$4x_1 + 21x_2 \leq 160{,}000$

A graphical representation of this situation is shown in figure 28.

Note that since the budget constraint is a $\leq$ type constraint, the only points which represent solutions that require less than $160,000 to implement lay below the budget constraint line. Therefore, none of the solutions that satisfy the budget constraint also satisfy the timber constraint. As a result, there are no solutions that simultaneously satisfy these constraints and there is no set of feasible solutions to this problem. Problems like this cannot be solved without reformulation to eliminate the infeasibility and this is possible only if the system being modified has a set of feasible solutions in the first place.

Unbounded Optimal Solution

Now we will modify the TR problem so that the optimal solution is unbounded. That is, at least one of the decision variables can take on arbitrarily large values and still be feasible. This situation occurs if we eliminate the acreage constraint from the original problem. A graphical representation of this situation is presented in figure 29.

Note that x_1 (acres managed for timber) can take on any value up to infinity. Since x_1 is now unbounded, it is possible to manage an unlimited number of acres for timber and generate unlimited net return. This is obviously an unrealistic situation and no realistic solution to the problem can be determined.

Because we have dealt only with small problems, it may seem that the conditions leading to no feasible solution or an unbounded optimal solution are easy to detect. For real world problems, however, such conditions are often difficult to identify. Most computer LP packages provide some clues as to the cause of an infeasibility or an unbounded solution, but these problems can be difficult to locate and solve even with this additional information. When large scale LP models are formulated, a great deal of time is often devoted to locating and correcting problems causing infeasibilities. It is important to realize that if the model is correctly formulated (i.e., if it is an accurate representation of the system), then an unbounded solution should not be present.

The following exercises refer to the TR model discussed above.

Exercise 13.—With reference to the original TR problem, suppose the acreage constraint is changed to:

$x_1 + x_2 = 100{,}000$ acres

How would this modify the set of feasible solutions for the problem? Graph this new set. From a management standpoint, what is the implication of this change in the acreage constraint? Will the optimal solution for the problem change?

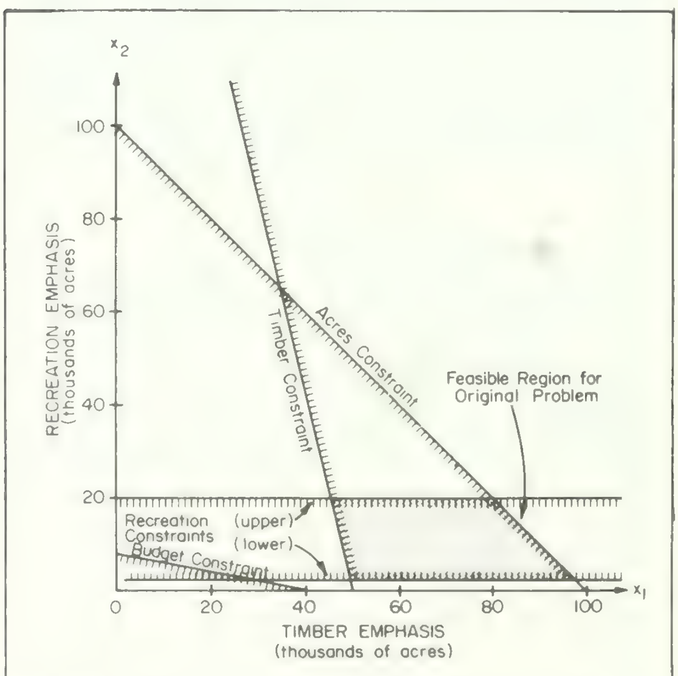

Figure 28.—Graphical representation of TR problem with budget limit of \$160,000.

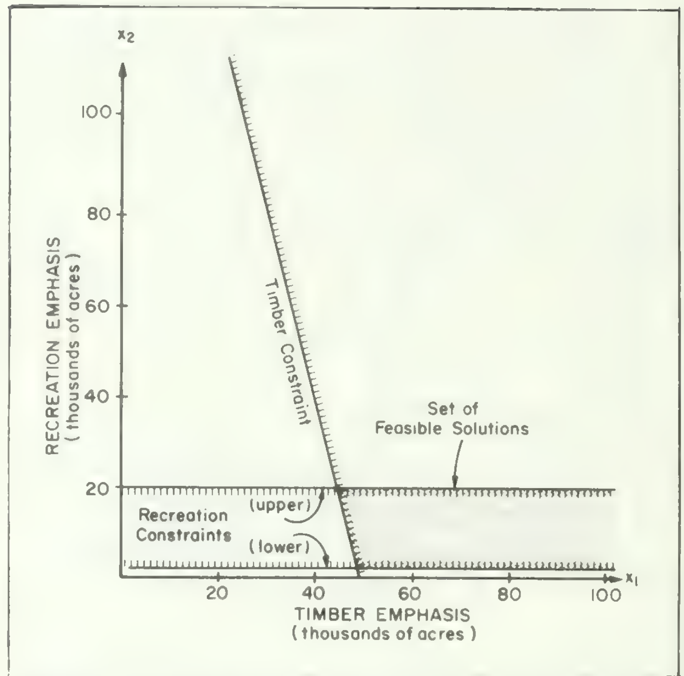

Figure 29.—Graphical representation of TR problem with no acreage constraint.

Exercise 14.—Consider the modified TR problem with the budget constraint:

$4x_1 + 21x_2 \leq 500{,}000$

as discussed in the text. We have identified the trade-offs in budget and revenue that result from the imposition of this constraint. Discuss all additional trade-offs that result from this new constraint. Be sure to calculate the actual amounts involved in each trade-off.

Exercise 15.—With reference to figure 27, reformulate the TR problem so that the budget constraint:

$4x_1 + 21x_2 \leq 750{,}000$

is no longer redundant. How many different constraints could be changed (one at a time) to accomplish this?

Exercise 16.—With reference to figure 28, reformulate the TR problem with the budget constraint:

$4x_1 + 21x_2 \leq 160{,}000$

so that there is a set of feasible solutions to the problem. Graph this reformulated problem, identify the set of feasible solutions, and determine the optimal solution. Do you have any redundant constraints in your reformulated problem?

Exercise 17.—Consider the original form of the TR model. Suppose we want to change the criterion of optimality to the minimization of budget expenditures. Also, suppose that we require that net returns must be at least \$400,000. All other requirements are as

given in the original problem. Formulate this new problem, write out the A matrix, B vector, draw a graphical representation of the problem, label the set of feasible solutions, and determine the optimal solution to the problem.

The following exercises deal with additional land management problems.

Exercise 18.—Curly Fuzz has 800 acres of land which is suitable for either camping or skiing. He also has allocated 100 hours of his own time per month to operate the enterprises. The camping enterprise can be operated 7 months of the year while skiing can be conducted for only 5 months. Each acre devoted to camping requires 1 man hour per year for operation and returns $20 net income. Skiing requires the same labor per acre but returns $30 net income per acre. What is the best mix of acres to devote to camping and skiing to maximize Fuzz's net income if a given acre can be used for one and only one enterprise (Duerr et al. 1975)?

Formulate this as a linear programming problem, draw a graphical representation of the problem, and determine the optimal solution.

Exercise 19.—Suppose you have 300 acres which may be regenerated by one of two possible methods, machine planting or aerial seeding. Each acre planted contributes $25 to your profit and each acre seeded contributes $10. Two man hours are expended in planting an acre while only one man hour is required to seed an acre. Lastly, machine planting an acre requires one planter machine hour while aerial seeding an acre requires one-fourth hour flying time. At most you can plan on 400 man hours, 200 planter machine hours, and 60 flying hours for the entire project. The objective is to maximize profits.

1. Formulate this as an LP problem.
2. Define all variables.
3. Draw a graphical representation of the problem.
4. Determine the optimal solution.

Exercise 20.—The Big'r-N-Hell Timber Company is bidding on a 100-acre block of timber on national forest land and wishes to know what revenue can be obtained from the harvest before bidding. The Forest Service has stated that at least 100 acre feet of water must flow down the stream after the cutting operation and that sediment production cannot increase by more than 40 tons. The firm can clearcut or cut selectively; the first method yields a profit of $500 per acre and the second yields $75 per acre. Clearcutting an acre produces 3 acre feet of water and increases sediment 0.5 ton while selective cutting produces 0.5 acre feet of water and increases sediment 0.1 ton. Set up a linear program that will maximize profit from timber harvesting on the 100 acres. Solve this graphically.

The following problems deal with complications arising from improper formulation. To answer them draw the graphical representation for each problem.

Exercise 21.—Can the following problems be solved as an LP problem? State why or why not.

$$\max Z = 5x_1 + 10x_2$$
$$\text{subject to: } 5x_1 - x_2 = 10$$
$$2x_1 - x_2 = 20$$

Exercise 22.—Can the following LP problem be solved? State why or why not.

$$\max Z = 5x_1 + 6x_2$$
$$\text{subject to: } 10x_1 + 10x_2 \leq 100$$
$$x_2 = 6$$

ADVANTAGES AND DISADVANTAGES OF LINEAR PROGRAMMING

As with any technique, Linear Programming (LP) has certain advantages and disadvantages which influence or limit its applicability. In this section, we will discuss the assumptions internal to linear programming and their influence on application of LP to land management problems. We will also compare LP with some other quantitative modeling techniques that may serve as alternatives.

ASSUMPTIONS OF LINEAR PROGRAMMING

The assumptions discussed include (1) linearity, (2) proportionality, (3) additivity, (4) non-negativity, (5) divisibility, (6) certainty, and (7) a single objective function.

Linearity

All mathematical relationships expressed in any LP model, either in the objective function or the constraints, must be linear in terms of the decision variables. That is, there cannot be any terms involving powers, cross-products, logarithms, etc. For example, the expressions:

$$\max Z = 16x_1 + 2x_2 + 4x_3$$
$$4x_1 + 5x_2 + 6x_3 \leq 100$$
$$x_1 + 9x_2 + 11x_3 \geq 50$$

are all linear, but the expressions:

$$\max Z = 16x_1^2 + 4x_1x_2 + 9x_3$$
$$19x_1^2 + 4x_1x_2 + 6 \log x_3 \leq 100$$
$$4x_1^2 + 11x_2^4 + 4x_1x_2x_3 \geq 50$$

are not linear. The last three expressions would be invalid expressions for inclusion in an LP model. They could, however, be incorporated in certain nonlinear programming models.

In order to satisfy the linearity requirement, two additional assumptions about relationships between decision variables are implied. These are known as proportionality and additivity and they must hold in the objective function and in all constraints.

Proportionality

Proportionality means that the measure of effectiveness (objective function) and rate of resource usage (constraints) must be proportional to the level of each activity conducted separately. For example, suppose that the objective function of interest involves profit maximization and that x_1 represents the number of acres on which a particular management prescription is applied. If the coefficient of x_1 in the objective function is $50, this means that each acre of land managed under the ap-

propriate prescription will yield a profit of \$50. That is:

if $x_1 = 1$, profit is \$50(1) = \$50;

if $x_1 = 49$, profit is \$50(49) = \$2,450;

if $x_1 = 50$, profit is \$50(50) = \$2,500.

Said another way, no matter how many acres are currently managed under this prescription (x_1), the rate of increase (decrease) in profit from this activity will be a \$50 per acre increase (decrease) in the number of acres managed.

Proportionality implies the same relationship for the variables and their coefficients in the constraints except that now the coefficients are a measure of rate of resource use rather than a measure of effectiveness. For example, suppose we have a constraint of the form:

$5x_1 + 10x_2 + 6x_3 \leq 4{,}000$

where 4,000 is the number of units of some resource that is available and, again, x_1 is the number of acres to be managed according to some management prescription. Proportionality means that no matter how many acres we manage under this prescription, each acre will consume 5 units of the resource.

Additivity

The assumption of proportionality alone is not enough to guarantee linearity; it is possible for interactions between activities to occur (represented mathematically by cross-product terms) with respect to total effectiveness or usage. To insure that this cannot happen, the assumption of additivity must be made. That is, the total effectiveness (objective function) and total resource usage (constraints) resulting from conducting two or more prescriptions at the same time must equal the sums of effectiveness or usage resulting from each activity being carried out separately.

For example, suppose the objective function is:

max profit $= 50x_1 + 30x_2 + 40x_3$

and x_1, x_2, and x_3 equal the number of acres managed under each of three different prescriptions. The coefficients represent the per acre profits for each. Further suppose that:

$x_1 = 20$ acres managed, prescription 1;

$x_2 = 30$ acres managed, prescription 2;

$x_3 = 40$ acres managed, prescription 3.

The assumption of proportionality guarantees that:

profit from prescription 1 = (50)(20) = \$1,000;

profit from prescription 2 = (30)(30) = \$900;

profit from prescription 3 = (40)(40) = \$1,600.

The assumption of additivity guarantees that the total profit from all three prescriptions will equal the sum of the profits resulting from each one separately. In this case:

profit = \$1,000 + \$900 + \$1,600 = \$3,500

The assumption of additivity implies the same thing with respect to rates of consumption of resources as expressed by constraints. That is, if our constraint is:

$5x_1 + 10x_2 + 6x_3 \leq 4{,}000$

and x_1, x_2, and x_3 have the values given above, then the assumption of proportionality guarantees that:

units of resource used by prescription 1 is (5)(20) = 100;

units of resource used by prescription 2 is (10)(30) = 300; and

units of resource used by prescription 3 is (6)(40) = 240.

The assumption of additivity guarantees that the total amount of resource used is the sum of amounts used by each prescription carried out separately. In this case, amount of resource used = 100 + 300 + 240 = 640 units.

Non-Negativity

As has been mentioned, it is assumed that all decision variables are non-negative or that they cannot take on negative values. This assumption is rarely violated in practice, particularly in land management applications. Even if it is violated, it presents no problem in solving the LP problems because of various tricks that can be applied.

Divisibility

This assumption refers to the ability of the decision variables to take on any non-negative value rather than just integer values. In other words, the decision variables are assumed to be continuous variables.

Certainty

It is assumed that all coefficients in the model (i.e., both those in the objective function and those in the constraints) are known constants. That is, an LP model is a deterministic model or one that involves no uncertainties or probabilistic elements.

A Single Objective Function

Linear programming is often criticized because it considers only one criterion of optimality (objective function) at a time. It is possible to optimize with respect to more than one criterion, but each must be considered separately. This can be done by repeatedly using the simplex method to determine the optimal solution corresponding to each objective function of interest. Simultaneous optimization for two or more criteria is possible only if they can be expressed in the same units and, thus, be incorporated in a single objective function. Criteria or objectives that cannot be expressed in the same units are often referred to as incommensurable objectives and simultaneous optimization of two or more of these is beyond the capability of any technique.

ADVANTAGES AND DISADVANTAGES OF LINEAR PROGRAMMING

Like all analytical techniques, the assumptions on which LP is based create advantages and disadvantages that influence its application. It is important to be aware of these and to recognize the limitations they imply. Linear programming has often been criticized for its disadvantages (i.e., linearity, lack of certain knowledge about the coefficients, lack of enough detail to adequately reflect reality, etc.), and while it is certainly important

to recognize these, it is just as important to realize that the alternatives to LP also have their disadvantages. Furthermore, LP possesses certain advantages that place it in a favorable position when compared to some of the alternative modeling techniques.

The Linearity Assumption: A Discussion

Perhaps the linearity assumption of LP has been the target of more criticism than any other aspect of the technique. While it is certainly true that the world is not linear, this restriction in an LP model may not be as serious a problem as some claim it is. One reason for this is that many nonlinear relationships can be approximated by linear ones. This is often done in a piecewise manner as is indicated by the examples in figure 30.

From these examples, it can be seen that one can closely approximate a nonlinear relationship with segments of straight lines. In such cases, a linear approximation is often sufficient, particularly when one considers our lack of knowledge about some aspects of natural resource systems.

A special type of linear programming known as separable programming is designed to handle nonlinear constraints by using a piecewise linear approximation like that shown in figure 30. Piecewise linear approximation of monotonically decreasing constraints (Case A in fig. 30) enables such relationships to be incorporated in conventional linear programming models. Such an approach has been utilized to handle downward-sloping demand curves in timber production (Hrubes and Navon 1976).

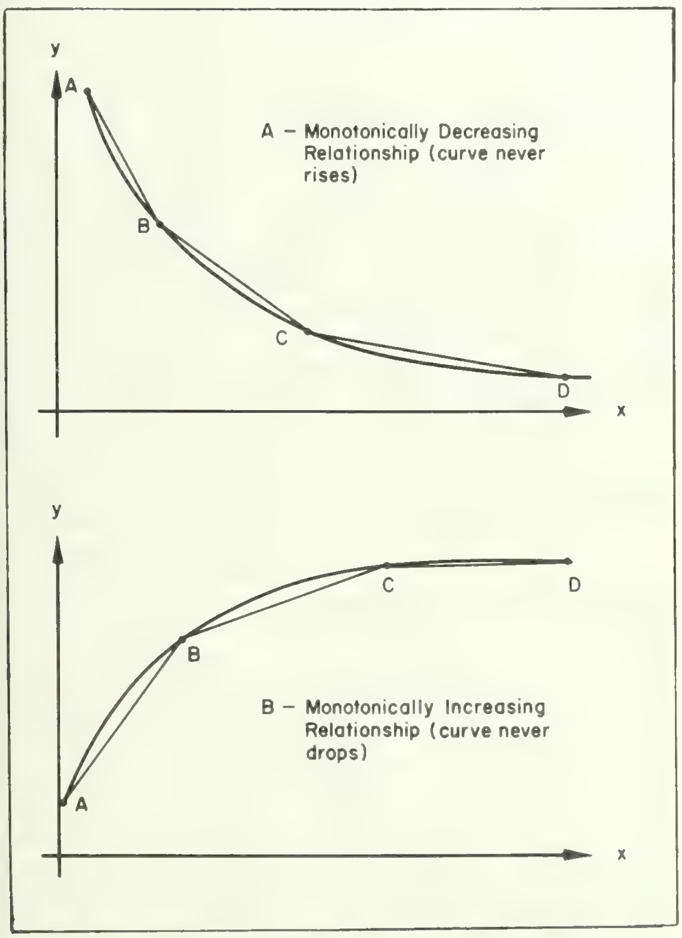

Figure 30.—Examples of piecewise linear approximation of nonlinear relationships.

If one simply cannot live with linear approximations of nonlinear relationships, there are various nonlinear programming techniques that permit inclusion of nonlinear constraints or objective functions in the model. Unfortunately, while nonlinear programming models can be formulated, solution of the same models is often not possible. This is particularly true as model size increases. In other words, we can relax the linearity assumption and formulate a nonlinear model, but once we have done this we have no guarantee that we can solve the problem. In linear programming, if all of the assumptions are met, the optimal solution can be determined if it exists.

It also turns out that if we happen to be able to solve our nonlinear programming problem, it will cost us more than it would for an LP problem of comparable size. This is because algorithms for solving nonlinear programming problems are more complex and computationally more inefficient than the simplex method. For large scale problems like those encountered in land management planning, the difference in costs can be quite significant. The guaranteed solution and computational efficiency of the simplex method are two factors that make it advisable to sacrifice nonlinearity for large scale problems.

The Divisibility Requirement: A Discussion

The divisibility requirement, or the assumption that the decision variables are continuous, can lead to problems. Often these variables represent quantities that have significance only at integer values. For example, it makes no sense to talk about 101.78 cattle, 2.63 campsites, or 1,050.92 deer. When this sort of thing happens, a common practice is to round down (i.e., 101 cattle, 2 campsites or 1,050 deer). This practice can be dangerous because it is possible that these rounded values are either infeasible or non-optimal. Mixed integer programming is a technique that handles problems with both continuous and discrete decision variables, but unfortunately, the solution algorithm, like those for nonlinear programming, can be inefficient and costly to use relative to the simplex method.

LP as a Deterministic Model: A Discussion

Our limited understanding of natural resource systems poses a problem because LP is a deterministic model. It implies that there are no unknown coefficients. This can make it difficult to assess both favorable effects such as board-foot yields per acre, cow-calf AUM's, and acre feet of water produced; and unfavorable impacts such as tons of sediment resulting from implementation of management prescriptions.

Furthermore, many of the coefficients are estimates of conditions or outputs that are to take place in the

future. Many land management LP models consider the scheduling of prescriptions in the future and do not consider the possibility that these activities may not occur. An LP model's allocation of acres to prescriptions is dependent, in part, on the quantities of different products that are produced since they are the measure by which the merits of each prescription are assessed. Thus, incorrect values for these coefficients can lead to a different allocation of acres and, hence, different levels of resource outputs than would be obtained if proper values were utilized.

Fortunately, the influence both of changed coefficients and of future changes in activities on the acreage allocation can be assessed through sensitivity analysis. Linear programming models with probabilistic components have been developed, but they suffer from the same disadvantages in terms of solution efficiency as nonlinear programming and mixed integer programming.

Nonquantifiable Benefits: A Discussion

Related to prescriptions whose beneficial effects are not quantifiable is the need to quantify the effects of management prescriptions. This limitation influences model development in the same way that uncertainty does. Examples include the printing of brochures designed to disperse recreation use, range practices that keep cattle away from heavily grazed areas, and research into particular aspects of the biological system being managed. The solution to this problem lies in the recognition that no single model or approach can incorporate all aspects of a "real world" problem. Specifically, only those practices that can be well quantified should be included in an LP model. That is, while the LP allocation of prescriptions may provide the basis of a plan, the complete plan will also include numerous items never considered by or incorporated in the model itself. In some cases, other analytical tools such as public involvement procedures and input-output analysis may be utilized to assess the merit of prescription (Betters 1977).

MODEL SIZE

Several of the above considerations relate to model size, a concept we have alluded to several times in this report. As mentioned above, one advantage of LP is that several thousand variables and mathematical relationships can be incorporated into a single model. Even so, there are problem size limitations in terms of model costs arising both from required computer solution time and storage requirements for the data included in the model. Even the most sophisticated computer LP solution packages have limitations on problem size, and in addition, output from very large problems can be difficult to interpret. As an example, the FMPS package on the system at Fort Collins cannot handle problems with more than 8,000 rows. In short, restricting the model by including only those factors that can be meaningfully quantified is an important consideration if LP is to be utilized effectively. Again, this is a reflection of the point made above that no single model can incorporate all aspects of a "real world" problem.

In conclusion, LP, like all modeling techniques, has numerous advantages and disadvantages. Important reasons for its being recommended for forest planning include:

1. It is one of few techniques that can be used to deal with problems of the size encountered in forest planning;
2. It is an optimization technique and, thus, may be used to satisfy some of the requirements in the NFMA regulations;
3. It is more nearly operational within the agency than other modeling techniques; and
4. There is some background of experience within the agency from prior LP modeling efforts.

It should not be implied from the preceding discussion that LP is the panacea to the forest planning problem that some believe it to be.

One does not simply formulate an LP, generate some runs, and have a set of forest plan alternatives. Considerable additional work is needed to take an LP solution and use it to develop an alternative plan.

Research is needed for the purpose of developing improved modeling approaches. For example, the fact that an LP model considers only a single objective function was mentioned earlier in this section. Land management planning on national forests must respond to many conflicting objectives, and the normal practice, in cases where LP has been applied, has been to determine the optimal solution for each objective of interest. The disadvantage of this approach is that each objective or criterion of optimality is considered more or less independently when simultaneous consideration of several objectives is desirable. Unfortunately, as was mentioned above, a single solution that optimizes a set of conflicting objectives simultaneously does not exist. Multiobjective optimization techniques should be investigated in order to determine their applicability to forest planning problems. Following is a brief introduction to one multiobjective technique, goal programming, which happens to be a special case of linear programming.

GOAL PROGRAMMING: A SPECIAL CASE OF LINEAR PROGRAMMING

As described above, one limitation of LP is the fact that it cannot deal with problems involving multiple incommensurable objectives. However, there is a class of techniques known as multiple optimization or vector optimization techniques that employ multiple decision criteria for the purpose of determining a preferred or satisficing solution to such problems.

The multiple optimization technique that has been applied most often is known as goal programming. While this technique is not the subject of this report, its usage is widespread enough to justify a brief introduction. The primary purpose of this introduction is to provide the reader with some insight into the relationship between the LP and goal programming (Field 1978, Field et al. 1980).

An Example

One way to introduce goal programming is by means of an example. Toward that end consider the following modification of Wilson's TR problem (see the Land Use Problem and Some Elementary Sensitivity Analysis section) into a goal programming problem.

Suppose the land manager has identified the following goals:

1. He would like to maximize the production of recreation visits.
2. He would like to harvest as much timber as possible.

In order to represent these goals in a goal programming model, it is necessary to quantify them by specifying targets. There are several ways of doing this, but a recommended procedure is to specify targets that correspond to the optimum level for each goal or criterion considered by itself. This can be done by solving two separate LP problems, one with an objective function that will maximize the production of recreation visits and the other with an objective function that maximizes timber harvesting. Each LP would have the set of constraints defined for the original Wilson's TR problem.

If the reader reviews the discussion in the Land Use Problem section and examines the graphical representation of Wilson's TR model in figure 24, it is easy to determine that the optimal solutions for each of the LP problems correspond to the corner points C and D of the set of feasible solutions. Thus, for the first goal:

the target value = 400,000 recreation visits

and this is obtained by managing 80,000 acres of timber ($x_1 = 80{,}000$) and 20,000 acres for recreation ($x_2 = 20{,}000$). For the second goal:

the target value = 39,400,000 board feet of timber

and this is obtained by managing 98,000 acres for timber ($x_1 = 98{,}000$) and 2,000 acres for recreation ($x_2 = 2{,}000$).

It should be obvious to the reader that the objective functions for each of the LP problems just discussed would be:

for goal 1: max recreation visits = $20x_2$;

for goal 2: max timber production = $400x_1 + 100x_2$.

Let us now consider a different way of expressing the objective functions that correspond to each of these goals. In doing so, we can examine one of the differences between LP and goal programming, this being the way in which the objective function is expressed.

Defining the First Goal

For now, consider only the first goal. The constraints for the original problem are:

$$\begin{aligned} x_1 + \quad x_2 &\le 100{,}000 \\ 400x_1 + 100x_2 &\ge 20{,}000{,}000 \\ 20x_2 &\ge 40{,}000 \\ 20x_2 &\le 400{,}000 \\ x_1 \ge 0,\ x_2 &\ge 0 \end{aligned}$$

The fourth constraint pertains to our recreation goal. In our discussion of the simplex method in the Land Use Problem and Some Elementary Sensitivity Analysis section, we introduced the concept of slack and surplus variables. Let x_3 be the slack variable for this constraint. Then we have:

$$20x_2 + x_3 = 400{,}000 \text{ visitor days.}$$

As we saw in the Land Use Problem section, x_3 measures the difference between the amount of visitor days produced and the limit of 400,000 imposed by the carrying capacity of the system. That is:

$$x_3 = 400{,}000 - 20x_2$$

This suggests that we can state the manager's recreation goal in terms of the slack variable x_3 because maximizing the production of recreation visits is equivalent to minimizing x_3 because, as discussed above, 400,000 visitor days is both the target for the goal and the maximum amount that can be produced. The goal programming formulation for the first goal considered above is:

$$\min Z_1 = x_3$$

subject to:

$$\begin{aligned} x_1 + \quad x_2 \qquad &\le 100{,}000 \\ 400x_1 + 100x_2 \qquad &\ge 20{,}000{,}000 \\ 20x_2 \qquad &\ge 40{,}000 \\ 20x_2 + x_3 &= 400{,}000 \\ x_1 \ge 0,\ x_2 \ge 0,\ x_3 &\ge 0 \end{aligned}$$

Note that this simple example of a goal programming problem is just a minimization LP problem with the objective function expressed in terms of a slack variable.

A characteristic of all goal programming problems is that their criteria of optimality involve the minimization of one or more slack and/or surplus variables. This is because goal achievement is expressed in terms of either the amount of underachievement (value of the slack variable) or the amount of overachievement (value of the surplus variable).

In goal programming, each goal can be defined in one of three ways. These are:

1. Both under and overachievement are possible;
2. Only underachievement is possible; or
3. Only overachievement is possible.

Since it has been determined that 400,000 visitor days is the carrying capacity limit, the second approach where only underachievement is possible is used in the above example. That is, the above problem formulation does not permit the production of more than 400,000 visitor days. If both under and overachievement were to be permitted (approach 1), then both a slack variable (which measures underachievement) and a surplus variable (which measures overachievement) would need to be defined. If only overachievement is permitted, then only a surplus variable is defined.

Defining the Second Goal

Now we shall consider the manager's second goal, that of maximizing timber production. Examination of the constraints for the original problem reveals that, unlike the case of the recreation goal, there is no constraint that reflects or incorporates the timber goal. If the constraint:

$$400x_1 + 100x_2 \le 39{,}400{,}000$$

is added to the problem, then it is possible to reflect the timber goal.

This is done in the same fashion as with the recreation goal. For example, a slack variable, say x_4, is de-

fined such that

$$400x_1 + 100x_2 + x_4 = 39{,}400{,}000$$

This slack variable measures the difference between the actual amount of timber produced and the target value. That is:

$$x_4 = 39{,}400{,}000 - 400x_1 - 100x_2$$

As with recreation goal, we can state the timber goal in terms of the slack variable, which in this case is x_4. We know from the above discussion that we cannot produce more than 39,400,000 board feet of timber. Since increasing the amount of timber produced is the same as reducing the value of x_4 (or vice versa), maximization of timber is achieved by minimizing x_4. The problem in terms of the timber goal is:

$$\min Z_2 = x_4$$

subject to:

$$\begin{aligned} x_1 + x_2 &\leq 100{,}000 \\ 400x_1 + 100x_2 &\geq 20{,}000{,}000 \\ 20x_2 &\geq 40{,}000 \\ 20x_2 &\leq 400{,}000 \\ 400x_1 + 100x_2 + x_4 &= 39{,}400{,}000 \\ x_1 \geq 0,\ x_2 \geq 0,\ x_4 &\geq 0 \end{aligned}$$

Note that the timber constraint has been added to the problem.

Dealing with Incommensurable Objectives

Up to now we have considered each goal separately. Since the goals are expressed in different units (board feet and visitor days), this is a situation where there are incommensurable objectives. Thus, simultaneous optimization of both of these goals as they are currently expressed is impossible. Two approaches to the solution of this problem that have been developed are cardinal weighting goal programming and pre-emptive ranking goal programming.

In the cardinal weighting approach, all goals are assumed to be in the same units and a single objective function is formulated. The coefficients in this objective function are, in effect, penalties for non-achievement of the various goals. In our example, suppose the objective function is:

$$\min Z = x_3 + x_4$$

In this case, both coefficients are 1 which means that the underachievement of the recreation goal has the same contribution per visit to Z as the underachievement of the timber goal does per board foot. In other words, the two goals have equal importance in this case. In a typical analysis using cardinal weighting, the coefficients or penalties must be differentially weighted in order to incorporate the decisionmaker's preferences. For example, a penalty of 1.5 might be attached to each visit by which the recreation goal is underachieved. The objective function (assuming the penalty for timber is unchanged) becomes:

$$\min Z = 1.5x_3 + x_4$$

This choice of penalties implies that the decisionmaker prefers underachievement of the timber goal (penalty of 1 per board foot) to the underachievement of the recreation goal (penalty of 1.5 per visit).

The problem with this approach lies in the choice of a single set of penalties or weights. For example, who is to say which of the sets of weights just given is better and why? Rather than doing this, a more rational approach is to consider several different sets of weights or penalties. This will result in the formulation of a number of objective functions and the problem can be solved for each one. Trade-offs between different levels of achievement of the goals can be determined and an analysis of these trade-offs can help the decisionmaker choose a preference structure for the goals being considered.

To properly apply this method, care must be taken in the choice of targets for each goal. An approach such as the one discussed above for the recreation and timber goals will insure that only non-inferior levels of goal achievement will be considered in the trade-off analysis. For any set of goals, a non-inferior set of achievement levels is defined to be one where there does not exist another feasible set of achievement levels, or where, for each goal, the actual achievement is at least as good as that for the set of achievement levels being considered. Said another way, inferior solutions lie in the interior of the feasible region rather than on the boundary.

For example, consider the following sets of achievement levels for the recreation and timber goals in Wilson's TR problem:

	Recreation	Timber
set 1	100,000	20,000,000
set 2	370,000	20,000,000
set 3	390,000	19,000,000
set 4	600,000	42,000,000

Clearly, set 2 is better than set 1 for recreation and equal to it for timber. Thus, set 1 is inferior to set 2 or, conversely, set 2 is non-inferior to set 1. Sets 2 and 3 are not comparable without additional information because one is better in recreation and the other is better in timber. (The same problem arises in a comparison of sets 1 and 3.) Set 4 is not feasible in terms of Wilson's TR problem, as we saw in the discussion of setting goal targets.

Setting targets, as was done for recreation, and then setting timber will ensure that sets like set 1 will not be considered in the trade-off analysis. Cardinal weighting goal programming is more efficient than LP for this type of analysis. For more detail on this approach, the reader is referred to the two papers by Field.

The pre-emptive ranking approach to goal programming considers each goal separately. In this approach, a priority or importance ranking is established and the achievement of the highest priority goal is considered first, after which the second priority goal is considered and so on for the remaining goals.

Suppose in our example that the recreation visitor day goal is assigned first priority and the timber goal second priority. In an attempt to satisfy the first priority goal, the following LP problem would be solved:

$$\min Z_1 = x_3$$

subject to:

$$\begin{aligned} x_1 + x_2 &\leq 100{,}000 \\ 400x_1 + 100x_2 &\geq 20{,}000{,}000 \\ 20x_2 &\geq 40{,}000 \end{aligned}$$

$$20x_2 + x_3 = 400{,}000$$
$$400x_1 + 100x_2 + x_4 = 39{,}400{,}000$$
$$x_1 \geq 0,\ x_2 \geq 0,\ x_3 \geq 0,\ x_4 \geq 0$$

Solution of this problem yields production of visitor days at the limit of feasibility or 400,000 as discussed above. In other words, this goal is completely achieved ($x_3 = 0$) which is to be expected because of the way in which we chose the target.

Before attempting to satisfy the second priority goal, a constraint would be added to the problem to ensure that the level of achievement of the first priority goal is not violated. In this example, a suitable constraint would be $x_3 = 0$. In an attempt to satisfy the second priority goal, the following LP problem would be solved:

$$\begin{aligned} \min Z_2 &= x_4 \\ x_1 + x_2 &\leq 100{,}000 \\ 400x_1 + 100x_2 &\geq 20{,}000{,}000 \\ 20x_2 &\geq 40{,}000 \\ 20x_2 + x_3 &= 400{,}000 \\ 400x_1 + 100x_2 + x_4 &= 39{,}400{,}000 \\ x_3 &= 0 \\ x_1 \geq 0,\ x_2 \geq 0,\ x_3 &\geq 0,\ x_4 \geq 0 \end{aligned}$$

The optimal solution to this problem is the same as given above for the recreation goal. In each case, a total of 34,000,000 board feet are produced. The amount of timber produced does not increase even when the timber goal is considered because to increase timber production would require a reduction in recreation visits (see fig. 24), thus violating the constraint $x_3 = 0$. Note that, in this case, the LP formulation and the pre-emptive ranking goal formulation yield exactly the same optimal solution. This is not ordinarily the case. For example, if one reverses the goal priorities (i.e., making timber priority 1, etc.), the optimal solution will correspond to point D in figure 24. The reader may find it useful to verify this.

Solution of a pre-emptive goal programming problem consists of the solution of each of a sequence of LP problems, one for each goal priority level that has been defined. Each succeeding LP problem is modified by the addition of constraints to ensure that the level of achievement of all higher priority goals is not violated. We saw this in our example with the addition of the constraint $x_3 = 0$ to the second LP problem to ensure that the level of achievement of visitor days not be reduced in attempting to satisfy the dollar benefits goals.

This characteristic of the pre-emptive ranking approach implies that goals at a given priority level are infinitely more important than those at lower priority levels. Suppose it were necessary to reduce the level of achievement of some goal by one unit in order to obtain one unit of a commodity associated with a lower priority goal. Since higher priority goal achievement cannot be violated, no units of the commodity associated with the lower priority goal would be produced. This implies that the last unit of the commodity associated with the higher priority goal is more important than the first unit of the commodity associated with the lower priority goal. Obviously, this is not very realistic since the trade-off between different commodities is rarely this clearcut in real world situations. A trade-off analysis using cardinal weighting goal programming, as discussed above, is more likely to reflect preferences in such situations.

Another disadvantage of the pre-emptive ranking approach is that it is possible that one will end up with an inferior set of goal achievement levels. This is especially true if goal targets are selected in an arbitrary fashion, as has often been done in cases where this technique has been applied. As discussed above, this is also a problem with cardinal weighting goal programming. However, because of the characteristics of pre-emptive ranking, there is no way to guarantee that only non-inferior sets will be considered as can be done with the cardinal weighting approach. This is due, in part, to the fact that in the cardinal weighting approach there is only a single objective function and, hence, only a single pre-emptive rank. Said another way, no goal can pre-empt any other. For a good discussion of the disadvantages of pre-emptive ranking goal programming, the reader is referred to the paper by Dyer et al. (1979).

To summarize this brief introduction to goal programming, the following points are worth noting:

1. Both types of goal programming are special cases of LP and have all of the advantages and disadvantages associated with the latter technique.
2. In addition, both approaches to goal programming suffer from the disadvantages outlined above.
3. The objective functions for goal programming are always expressed in terms of slack and surplus variables. In goal programming terminology, these are called deviational variables because they measure the amount of deviation between actual goal achievement and the desired goal level. They are usually denoted by d– for underachievements and d+ for overachievements.
4. In the pre-emptive ranking approach to goal programming, the final solution may be sub-optimal or inferior in that it lies on the interior of the feasible region. This is caused by the infinite weights described above for higher priority goals. Such a solution is sometimes called a *satisficing* solution.
5. Properly formulated cardinally-weighted goal programming can, more conveniently than LP, produce the trade-off surface in a multiple criterion problem and provide the basis for a compromise solution that is non-inferior.

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Kent, Brian M. 1988. Forest Service land management planners' introduction to linear programing. Gen. Tech. Rep. RM-173. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

This report provides a detailed explanation of basic concepts of linear programming (LP) for forest planners and others who must use the technique to develop national forest land management plans. The role of LP in national forest planning analysis is presented. Basic algebraic concepts needed to understand LP are reviewed. The various components of an LP model are described and the advantages and limitations of the technique are discussed. Examples are presented in order to illustrate the technique, how it is used to formulate forest planning models, and how it is used in the Forest Service land management planning process. Procedures for solving LP models and the technique goal programming are also discussed. No prior background in operations research is assumed on the part of the reader.

Keywords: Management Planning, Linear Programming, Goal Programming, Multiple Use Management

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins
Colorado 80526

**General Technical
Report RM-174**

Basic Assumptions

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Section 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number af assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

Basic Assumptions

Contents

Basic Assumptions

Major Changes in Assumptions

There have been many changes in the U.S. economy in the decade, 1979-1989. During this decade, trade and budget deficits, interest and inflation rates, and energy costs have influenced short- and long-term prospects for the U.S. economy. Despite the many short-run shocks to the economy during the past decade, the general outlook for the broad measures of economic activity is one of growth and increasing affluence of the U.S. population. This outlook parallels the history of the past 50 years during which the U.S. economy was buffeted by world war, recession, and other dislocations but still managed to more than quadruple its gross national product net of inflation and deflation.

There are four major revisions in the basic assumptions underlying the RPA Assessment—projections of population, gross national product, energy prices, and per capita consumption of beef, veal, lamb, and mutton. These revisions were made based on new information obtained since the basic assumptions were made for the 1979 RPA Assessment.

Population

For the 1979 RPA Assessment, population was projected under three sets of assumptions termed "low," "medium," and "high." In most subsequent analysis in the Assessment, the medium projections were given emphasis. For the 1989 RPA Assessment, only one population projection was made. It used the Bureau of the Census middle series projection with a high immigration assumption (750,000 per year). The high immigration assumption is an attempt by the Bureau of the Census to account for net illegal immigration. The 1989 RPA Assessment projections of population for 2030 are about 8% higher than the medium projections for the 1979 RPA Assessment (table 1). This largely reflects the higher immigration assumption.

Gross National Product

The 1979 Assessment had low, medium, and high projections of gross national product. As shown in table 2, the 1989 RPA Assessment projection is lower than the medium projection from the 1979 RPA Assessment until 2020. By 2030, the projection from the 1989 RPA Assessment is about 8% higher.

Per capita disposable income in 2030 was assumed to be $25,840 for the medium projections in the 1979 RPA Assessment and $23,530 in the 1989 RPA Assessment. For both Assessments, the income projections indicate rising affluence of the U.S. populace, with real per capita purchasing power more than doubling by 2040 for the 1989 RPA Assessment.

Energy Costs

There were no explicit energy cost projections for the 1979 RPA Assessment. For the 1984 Supplement to the 1979 RPA Assessment, energy price assumptions were:

Table 1.—Projections of U.S.population (million) from the 1979 and 1989 RPA Assessments.

Year	1979 Assessment			1989 Assessment
	Low	Medium	High	
2000	245.9	260.4	282.8	274.9
2010	250.9	275.3	315.2	294.3
2020	253.0	290.1	354.1	312.1
2030	249.3	300.3	392.8	325.5
2040	N.A.	N.A.	N.A.	333.4

Table 2.—Projections of U.S. gross national product (in billions of 1982 dollars) from the 1979 and 1989 RPA Assessments.

Year	1979 Assessment			1989 Assessment
	Low	Medium	High	
2000	5,180	5,780	6,470	5,402
2010	6,320	7,400	8,710	7,031
2020	7,330	9,010	11,140	9,166
2030	8,600	11,100	14,410	11,957
2040	N.A.	N. A.	N.A.	15,627

Year	1984 Supplement	1989 RPA Assessment
	—cost per barrel (in 1982 dollars)—	
2000	99.06	29.68
2010	114.90	47.27
2020	133.23	50.00
2030	133.23	50.00
2040	N.A.	50.00

The projections for the 1989 RPA Assessment are considerably lower than for the Supplement, based, in part, on the softness of energy prices in the 1980's. There is much uncertainty about future crude oil prices, however. For the 1989 RPA Assessment, prices were arbitrarily leveled at $50, on the assumption that at this price, conservation and use of substitute energy sources would become wide-spread.

Beef, Veal, Lamb, and Mutton Consumption

The 1979 RPA Assessment projected low, medium, and high levels of consumption of beef, veal, lamb, and mutton. The 1989 RPA Assessment assumes that total consumption of these types of meat will remain at 110 pounds per capita per year throughout the projection period. As shown in table 3, per capita consumption projections for the 1989 RPA Assessment are considerable lower than for the 1979 RPA Assessment.

This change in assumption is based on the trend in actual consumption over the past decade, a growing awareness of the importance of diet in personal health, and the price competitiveness of poultry and other substitute foods. Also, many Americans' daily diet is one of choice, whereby increased incomes may affect the variety of foods eaten, but not the quantity.

Introduction

The decade of the 1980's has been characterized by sudden and far-reaching changes in the short-run context for making long-term projections, especially for fiscal and monetary policies and energy prices. In making the general assumptions for the Assessment and Appraisal, there is little basis for judging the accuracy of predictions about long-run levels of population and economic growth, or any of the other determinants of demands and supplies. The intent is to make assumptions, based on historical trends, knowledge about developments which affect these trends, and reasonable expectations about future changes. Because of the uncertainty of long-run projections, alternative futures are analyzed in the Assessment. These futures are based on assumptions about alternative values for variables that could significantly affect demands and/or supplies of soil, water, forest and range land resources.

Historical trends underlying the basic assumptions are shaped by massive social, political, technological, and institutional forces that are not easily or quickly changed. Recent trends are likely to persist over the long run with some short-term fluctuations.

Table 3.— Projections of per capita consumption of beef, veal, lamb, and mutton (pounds carcass weight) from the 1979 and 1989 RPA Assessments.

Year	1979 Assessment			1989 Assessment
	Low	Medium	High	
2000	140	141	143	110
2010	141	145	147	110
2020	138	145	148	110
2030	137	148	153	110
2040	N.A.	N.A.	N.A.	110

Population

Changes in population greatly affect the demands placed upon the Nation's soil, water, forest, and range land resources. These changes in population also influence the size of the labor force, a major determinant of the level of economic activity and related materials use.

In the past 50 years, the population of the United States increased by more than 100 million people (table 4). Projections of the WEFA Group, based on projections of the Bureau of the Census, indicate that population is likely to continue to grow during the next 50 years. The WEFA Group projections using the Census Middle Series projections with a high immigration assumption—the projections used in the Assessment and Appraisal—show annual population growth declining from about 1% in the 1970's to 0.2% in the decade 2030-2040.

The decline in the rate of population growth reflects the Bureau of the Census assumptions about fertility rates. Fertility rates have fluctuated widely in recent decades, but since the 1950's have fallen sharply. The medium projection is based on an assumed fertility rate of 1.9—a level close to current birth expectations of females of child-bearing age. The current fertility rate is below this figure, and approximates a level which would end population growth in the first part of the 21st century.

Legal immigration accounts for a significant part of U.S. population growth. Projections of population (table 4) assume net immigration of 750,000 people per year. This assumption is an attempt by the Bureau of the Census to account for net illegal immigration.

Geographic distribution of population has a strong influence on state and regional demands for many products, particularly those that must be produced and

consumed at the same place. State projections prepared by the Bureau of Economic Analysis are used as the basis for regional projections of demands upon soil, water, forest and range land resources. The Bureau projections show significant differences in population trends among the states and regions. Generally, the fastest growth is projected to be in the South and on the Pacific Coast. Rapid growth also is projected in some areas of the Rocky Mountains. The major population concentrations, however, remain in the North Central Region, and along the Atlantic and Pacific coasts.

The age distribution of the population is another significant factor in estimating demands for many products. The Bureau of the Census projection by age classes indicates a substantial increase, during most of the projection period, in the number and proportion of people in the middle-age classes—the classes that have the highest income levels and the largest demands for goods and services.

Gross National Product

In recent years, changes in the consumption of many soil, water, forest, and range land products have been closely associated with changes in the Nation's gross national product.

Between 1929 and 1986, the gross national product, measured in constant 1982 dollars, increased more than five times (table 4). Annual changes have fluctuated widely, from as much as 18.8% to -19%. The highest sustained rate of growth occurred in the 1960's, when it averaged 4.2% per year.

The wide fluctuations in annual rates of growth in the gross national product have reflected factors such as differences in the rates of change in the labor force, rates of unemployment, hours worked per year, and productivity. These factors probably will continue to cause fluctuations. The WEFA Group projections have business cycles with downturns in the economy in 1990,

Table 4.—Population, gross national product, and disposable personal income in the United States, selected years 1929-86, with projections to 2040.

	Population		Gross national product		Disposable personal income		Per capita disposable personal income	
Year	Millions	Annual rate change	(billions 1982 dollars)	Annual rate change	(billions 1982 dollars)	Annual rate change	1982 dollars	Annual rate change
1929	121.8	—	709.6	—	498.6	—	4091	—
1933	125.7	0.8	498.5	-8.4	370.8	-7.3	2950	-7.8
1940	132.1	0.9	772.9	7.9	530.7	6.2	4017	5.4
1945	139.9	1.1	1354.8	-1.9	739.5	-1.3	5285	-2.4
1950	152.3	2.1	1203.7	8.5	791.8	8.0	5220	6.2
1955	165.9	1.8	1494.9	5.6	944.5	5.6	5714	3.8
1960	180.7	1.6	1665.3	2.2	1091.1	2.2	6036	.1
1965	194.3	1.3	2087.6	5.8	1365.7	5.8	7027	4.5
1970	205.1	1.2	2416.2	-.3	1668.1	4.3	8134	3.1
1975	216.0	1.0	2695.0	-1.3	1931.7	1.9	8944	.9
1976	218.0	1.0	2826.7	4.9	2001.0	3.6	9175	2.6
1977	220.3	1.0	2958.6	4.7	2066.6	3.3	9381	2.2
1978	222.6	1.1	3115.2	5.3	2167.4	4.9	9735	3.8
1979	225.1	1.1	3192.4	2.5	2212.6	2.1	9829	1.0
1980	227.7	1.2	3187.1	-0.2	2214.3	0.1	9722	1.1
1981	230.1	1.0	3248.8	1.9	2248.6	1.5	9769	0.5
1982	232.5	1.0	3166	-2.5	2261.5	0.6	9725	-.5
1983	234.8	1.0	3279.1	3.6	2331.9	3.1	9930	2.1
1984	237.0	0.9	3501.4	6.8	2469.8	5.9	10419	4.9
1985	239.3	1.0	3607.5	3.0	2542.2	2.9	10622	1.9
1986	241.6	1.0	3713.3	2.9	2645.1	4.0	10947	3.1
PROJECTIONS								
2000	274.9	0.7	5402	2.8	3827	2.4	13920	1.6
2010	294.3	0.6	7031	2.6	4922	2.3	16730	1.6
2020	312.1	0.5	9166	2.8	6136	2.4	19660	1.8
2030	325.5	0.3	11957	2.7	7660	2.2	23530	1.9
2040	333.4	0.2	15627	2.7	9599	2.3	28790	2.1

Sources: Historical Data: Council of Economic Advisors 1987. Economic Report of the President. Feb. U.S. Gov. Print. Off. Washington, DC. Projections: The WEFA Group Special Report to the Forest Service. Copy on file with USDA Forest Service, Washington, DC.

1998, and 2003. After 2003, no attempt was made to project business cycles, and economic growth is assumed to increase smoothly. The assumed rates of growth in gross national product lead to a value of $5.4 trillion (1982 dollars) in 2000—1.45 times that of 1986 (table 4). By 2040, this projection would reach $15.6 trillion—4.2 times that of 1986.

The composition of outputs from the U.S. economic system will partly determine the types of materials needed by the economy. Available projections indicate that transportation, trade, and other services may account for a slowly growing share of total economic activity. Even though there is some decline in their relative importance, the expected increases in manufacturing and construction activities are large. This means that the U.S. economy probably will continue to produce large quantities of physical goods. In turn, large supplies of energy, minerals, and other raw materials will be needed to produce these goods.

The future adequacy of supplies of raw materials to meet the Nation's needs continues to be a concern despite the deflationary environment of the mid-1980's. Concern is also evident about the ways the various programs designed to protect or improve the environment will affect the kinds of goods produced, productivity, and various other factors which determine the rate of growth in economic activity. Despite these uncertainties, there is no apparent basis to assume that the growth trends of the past will not continue into the future.

Disposable Personal Income

Disposable personal income (i.e., the income available for spending or saving by the nation's population) is another important determinant of the demand upon soil, water, forest, and range land resources.

Projections of disposable personal income made by the WEFA Group show that disposable personal income would increase to $9.6 trillion by 2040 under the terms of the underlying assumptions—3.6 times the level of 1986 (table 4).

These assumptions indicate that per capita disposable personal income will rise to $28,790 by 2040—2.6 times the 1986 average. This growth means that the Nation will have a growing population with much greater purchasing power than today.

Institutional and Technological Change

Institutional and technological changes have substantially influenced demands upon soil, water, forest, and range land resources. These changes also have influenced supplies of many renewable resources. For the Assessment and Appraisal, it was assumed that a stream of institutional and technological changes would continue and would affect demands and supplies of the various renewable resources. It was also assumed that the effects of these changes would be similar to those that have taken place and that are accounted for in the historical data used in preparing the projections. Assumptions about important technological changes affecting crop and product yields and other uses of the renewable resources are specified in the Assessment and Appraisal reports. Other important assumptions for agriculture are discussed in later sections of this report.

Institutional changes that lead to the reservation of forest and range lands for designated uses such as wilderness, parks, and wildlife refuges have occurred for a long time; this development is considered in the projections of forest and range land areas.

Energy Costs

The long-term outlook for energy costs can be confusing because of the weakness of energy prices in the 1980's. According to Wharton Econometric Forecasting Services, worldwide demand for crude oil is likely to approach capacity levels around 2000, even without production restraint by the Persian Gulf countries. This consumption growth, by steadily depleting oil reserves, will create significant upward pressure on real oil prices in the 1990's and beyond. Projections of the Department of Energy show world oil prices increasing from 1986 levels of $13.97 per barrel to $51.10 per barrel in 2010 ($1982). If the Department of Energy projections were extended to 2040 based on the relationship between energy prices and gross national product, the price per barrel would be near $100 in 2040. This price was judged to be so high as to be unreasonable.

Conservation and development of alternative energy sources would act to slow the rate of increase in energy prices. For the purposes of this Assessment, the price per barrel is assumed to level off at $50 in 2020 and stay at this price through 2040. The price of $50 is assumed to be high enough to stimulate development of alternative energy sources with implications for the demand for timber and timber products, especially fuelwood. The following world oil prices are assumed for the 1989 RPA Assessment:

Year	Dollars per barrel
	(constant $1982)
2000	29.68
2010	47.27
2020	50.00
2030	50.00
2040	50.00

Various mathematical models were used in the second RCA Appraisal. Two key models were the National Interregional Agricultural Projection System (NIRAP) and a national linear programming model developed by the Center for Agricultural and Rural Development (CARD). The NIRAP model incorporates basic assumptions such as GNP and other projections of macroeconomic variables with various statistical relationships to estimate production, domestic demand, imports, and exports of the primary agricultural commodities. It is a predictive model in that it is an attempt to simulate the actual behavior of agricultural markets. The CARD model determines the least cost method of allocating resources to produce specified levels of crop and animal products. The CARD model does not attempt to simulate actual behavior of U.S. agricultural markets. Instead, it assumes that the U.S. agricultural sector operates efficiently and allocates production among regions so as to minimize costs of production.

The CARD model uses energy prices as an input, but is not designed to measure the impacts of changes in relative prices of energy on the structure of the agricultural sector. The prices of the various energy sources are used in the CARD model to compute a composite energy cost based on quantities and types of energy required by agriculture. These prices were developed from the Farm Enterprise Data System (FEDS). In the CARD model, relative prices of energy were assumed to be unchanged through the projection period.

Capital Availability

Much capital will be required to make the necessary investments in management, physical facilities, and processing plants to accommodate increased demands for forest and range land resources and agricultural products. The question of capital availability was addressed in the 1979 RPA Assessment and was judged not to be an obstacle to industry expansion. This judgment is supported by more recent assessments of capital availability in the future. For example, for the period through 2005, Wharton Econometric Forecasting Associates expects fixed investment growth to be strong, with an average growth rate of 2.9% per year. Wharton expects investment in plant and equipment to average 5.1% growth per year for durables manufacturing and 3.9% for nondurables. This kind of growth is consistent with historical investment levels. For example, investment in producers' durable equipment increased at an average annual rate of 6.5% in the 1960's and 5.2% in the 1970's.

Given the projected increases in gross national product expected to be generated by the U.S. economy after 2005, there is no basis for expecting a change in the situation for capital availability depicted by Wharton through 2005. Therefore, it has been assumed that capital availability will not significantly constrain long-term economic growth in general or intensified use of forest, range, and agricultural lands.

Beef, Veal, Lamb, and Mutton Consumption

Per capita consumption trends for meat—beef, veal, lamb and mutton—from domestic animals that graze will greatly influence the need for rangeland, feed grains and roughages.

Annual per capita consumption of beef, veal, lamb, and mutton declined from a record-high of 133.3 pounds in 1976 to about 110 pounds (carcass weight) in recent years. Possible reasons for this downturn include changing tastes and preferences and relative prices of other food products. The 1984 Forest Service Supplement assumed that per capita demand for beef, veal, lamb, and mutton would rise to 148 pounds by 2030. The Second Appraisal used the estimates in table 5. The 1989 RPA Assessment assumes that per capita consumption of beef, veal, lamb, and mutton will remain stable at 110 pounds per annum through 2040. Even stable per capita consumption would lead to increased demand because of population increases.

Distribution of Agricultural Trade Among U.S. Ports

The distribution of U.S. agricultural exports and imports among major ports is determined by many variables. Some of the more important ones are the quantity and location of foreign and domestic demand, inland and ocean transportation rates, and port and storage handling capacity. A panel of commodity, international agricultural trade, and transportation specialists used a modified Delphi approach to project the future distribution of exports and imports for the port areas of Atlantic, Great Lakes, Gulf and Pacific for 1990, 2000, and 2030. The assumed distribution of exports and imports was used to allocate the distribution of the exports and imports computed with the NIRAP model.

Land Areas by Class of Land

Various systems have been developed to classify land areas by type of land in the United States. Seemingly minor differences in criteria for classification can lead to significant differences in area by class of land. The data in table 6 show, as of 1982, those classes of land that the Forest Service and Soil Conservation Service have reconciled. These data were used in the 1984 Forest Service

Supplement and the Second SCS Appraisal. These data are also used in the 1989 RPA Assessment.

The 1982 National Resources Inventory (NRI) compiled by the Soil Conservation Service was the source of data for the land base used in the CARD model. The number of acres available were estimated for each RCA land group and divided into dryland and irrigated acres for the 105 producing areas used in the CARD model.

Projections of Land Area by Cover Type

The Second RCA Appraisal and the 1989 RPA Assessment differ in their needs regarding land area projections. The Appraisal projections start with existing crop and pasture area and projections of future levels of crop and animal production at the national level. The linear programming model—CARD—then allocates crop and animal production among regions to minimize the costs of production of the specified output levels. Forest land areas are specified by assumption and are used as inputs into the CARD model. With these procedures and the other assumptions in the CARD model, the findings of the Second RCA Appraisal (Review Draft) suggest that there will be more than enough cropland to produce projected output levels. Considerable acreages of cropland are assumed to go idle and no attempt is made to specify the type of cover that might develop on idle cropland.

Table 5.— Per capita consumption of selected food products (pounds per person) in 2000 and 2030 assumed for the Second RCA Appraisal.

Item	1982		2000		2030	
	retail wt.	carcass wt.	retail wt.	carcass wt.	retail wt.	carcass wt.
Beef	77	104	80	108	80	108
Veal	2	2	2	2	2	2
Pork	60	65	60	65	60	65
Lamb	2	3	2	3	2	3
Total red meat	141	174	144	178	144	178
Chicken[1]						
broilers	NA	49	NA	55	NA	55
mature chickens	NA	3	NA	3	NA	3
Turkey[1]	NA	11	NA	13	NA	15
Total poultry	NA	63	NA	71		73
Total red meat and poultry	NA	237	NA	249	NA	251
Dairy products[2]	540		520		510	
Eggs[3]	36		33		30	
Fish	13		18		27	

Source: Future Agricultural Technology and Resource Conservation, Iowa State University Press. 1984.

[1]*Ready-to-cook.*
[2]*Fresh milk equivalent.*
[3]*Pounds.*

Table 6.—Land areas in the United States by class of land.[1]

Class of land	Area *(thousand acres)*
Non-federal land:	
Crop[2] and pasture land[3]	529,851
Rangeland[4]	44,466
Transition land[5]	35,603
Forest land[6]	409,284
Other land[7]	159,776
Total, nonfederal	1,575,980
Federal land:	
Rangeland[4]	328,887
Forest land[6]	276,417
Other land[7]	73,504
Total, federal	687,808
Total land	2,254,788
All land:	
Crop[2] and pastureland[3]	529,851
Rangeland[4]	770,353
Transition land[5]	35,603
Forest land[6]	685,701
Other land[7]	233,280
Total land	2,254,788

[1]*Data as of 1982.*

[2]*Land use for the production of adapted crops for harvest, alone or in rotation with grasses and legumes. Adapted crops include new crops, small grain crops, hay crops, nursery crops, orchard and vineyard crops, and other similar specialty crops.*

[3]*Land used primarily for the production of adapted, introduced, or native forage plants for livestock grazing. Pastureland may consist of single species in a pure stand, grass mixture, or grass-legume mixture. Cultural treatment in the form of fertilization, weed control, reseeding, or renovation is usually a part of pasture management in addition to grazing management. Native pasture is included in pastureland in these land areas statistics.*

[4]*Land on which the climax vegetation (potential natural plant community) is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing and browsing. It includes natural grasslands, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities. It also includes areas seeded to native or adapted introduced species that are managed like native vegetation.*

[5]*Land that meets the definition of forest land based on cover characteristics, but where the predominant vegetation is grass or forage plants that are used for grazing. The Soil Conservation Service has classified and reported most of the lands as rangeland; the Forest Service has classified and reported these lands as forest land. In most instances, these lands are noncommercial timberland ecosystems such as pinyon-juniper, chaparral, and post oak. Transition land is an interim category used in this report to classify part of the area in such ecosystems. Work is underway in the Forest Service and Soil Conservation Service to resolve classification differences and show all such land as rangeland or forest land in future reports. Some of the area in noncommercial timberland ecosystems is classified as forest and range land in this report.*

[6]*Land at least 10% stocked by forest trees of any size, or formerly having had such tree cover and non currently developed for nonforest use. The minimum area for classification of forest land is 1 acre and must be at least 100 feet wide. Forest land is distinguished from rangeland in transition vegetation types if the tree canopy cover exceeds 10%. Forest lands include cutover areas temporarily unstocked as well as young stands and plantations established for forestry purposes which do not yet have 10% crown cover.*

[7]*A category of land cover and land use that includes farmsteads, other land in farms, strip mines, quarries, gravel pits, borrow pits, permanent snow and ice, small built-up areas, and all other land that does not fit into any other land cover land use category.*

The 1989 RPA Assessment uses predictive instead of normative models such as CARD. For the 1989 RPA Assessment, projections were needed for the area of range and forest cover. The Assessment projections used as a starting point the data which were reconciled by the two Agencies for 1982. Projections of range area were then based on area trends in the NIRAP projections. The national range area data were disaggregated to regions as necessary in the 1989 RPA Assessment, based on expert judgment and the NIRAP projections of changes in land area (table 7). Forest land area is expected to decrease and other land area to increase through the projection period.

Agricultural Technology

In the Second Appraisal, projections were made to the year 2030. These projections required many assumptions about growth factors influencing the supply and demand of agricultural products. A major assumption is the rate of growth in agricultural production technology. Changes in efficiency of production inputs, crop yield, and animal product output are considered in the Appraisal and Assessment.

Changes in the rate of growth in technology can be expressed as "agricultural productivity" or "crop production technology" growth rates. The question in both cases is how much output can be produced from a given set of the resources. In the Second Appraisal, both agricultural productivity and crop and animal production growth rates were used. Agricultural productivity is the flow of outputs (quantity produced) relative to inputs (resources used), and generally includes labor, land, services, and capital. It is a composite percentage change in technology. An increase in agricultural productivity may result from an increase in outputs or a decrease in inputs. Agricultural productivity would increase if plant and animal yields remain constant and resources used to achieve a given output level decrease.

Crop and livestock annual growth rate in production technology is an individual animal or crop yield response to management, genetics, or other inputs, such as fertilizer rates, placement of fertilizer, feeds, pesticides, etc. It does not include land or labor and some other capital inputs. This technology change is expressed as a percent change in yield for an individual crop or animal. A production technology increase in output of a crop or animal can result from additional inputs or better efficiency (genetic improvement) from the inputs being applied.

After a review of available information, it was assumed that the composite agricultural productivity rate of increase would be 1.6% per year, based on current knowledge. The productivity of rangeland was assumed to increase 0.7% per year. These annual increases were assumed for the period, 1980-2030.

For the major food and fiber crops and animals, assumptions about the annual rate of growth in production technology were based on the results of a USDA symposium[1] held in December 1982. These assumptions are the estimates made by a team of experts for the 11 major crops, livestock, and poultry shown in tables 8 and 9. These estimates were used rather than the composite 1.6% where possible. The most probable estimates shown in table 8 were used in the Appraisal base scenarios.

Table 7.—Average of land area (million acres) by type, 1982, with projections to 2040.

Year	Forest	Range	Other	Total
1982	722	770	763	2,255
2000	717	806	729	2,252
2010	714	806	730	2,250
2020	709	807	732	2,248
2030	703	807	736	2,246
2040	696	807	741	2,244

Table 8.—Annual growth rates (percent) in production technology for selected crops by confidence of estimate, 1982-2000, 2001-2030, and 1982-2030.

Confidence estimate and time period	Crop					
	Feed-grains	Alfalfa	Wheat	Cotton	Rice	Soybean
Most probable						
1982-2000	1.89	1.02	2.28	1.01	3.30	2.65
2001-2030	1.20	0.75	0.96	0.96	0.75	1.07
1982-2030	1.46	.85	1.46	.98	1.93	1.66
High						
1982-2000	2.65	2.09	3.16	1.89	5.22	4.48
2001-2030	1.50	1.24	1.20	.65	.61	0.81
1982-2030	1.93	1.56	1.93	1.11	2.33	2.17
Optimistic						
1982-2000	3.93	2.65	3.93	3.93	6.29	5.22
2001-2030	1.36	1.50	1.36	1.36	.52	1.58
1982-2030	2.32	1.93	2.32	2.32	2.64	2.93
Low						
1982-2000	1.02	.53	1.25	0	2.28	1.47
2001-2030	.75	.43	.61	.61	.96	.7
1982-2030	.85	.47	.85	.38	1.47	.98

Feedgrains consist of barley, corn, corn silage, oats, sorgum, and sorgum silage.
Source: Future Agricultural Technology and Resource Conservation, Iowa State University Press, 1984

Land Conversion Rates

The Federal and private land base can be used for many purposes and can be converted from one purpose to another. Generally, the land base is classified by use as forest, range, pasture, cropland, and urban, and other.

Table 9.—Annual growth rates (percent) in production technology by type of animal and unit, 1982-2000, 2001-2030, and 1982-2030.

Type of animal	Unit	1982-2000	2001-2030	1982-2030
Beef	Liveweight marketed per breeding female	1.2	1.0	1.0
Pork	Liveweight marketed per breeding female	1.6	0.7	1.0
Dairy	Milk marketed per breeding female	1.6	1.0	1.0
Sheep	Liveweight marketed per breeding female	1.6	1.0	1.1
Broiler				
Chickens	Liveweight marketed per breeding female	1.4	.2	0.6
Turkeys	Liveweight marketed per breeding female	1.8	0	.7
Laying hens	Number of eggs	1.0	.2	.5
Catfish	Age to one pound	2.2	3.1	2.3

Source: Future Agricultural Technology and Resource Conservation, Iowa State University Press, 1984.

For the purposes of the Appraisal, it was assumed that to the year 2030, agricultural and forest land would be converted to non-agricultural uses at the rate of 1.5 million acres per year. It was further assumed that of the 1.5 million acres, 63.8% would come from cropland, 17.5% from pasture, 13% from forest, and 5.7% from other sources.

Over time, it could reasonably be expected that land would shift from one use to another, depending on the relative economics of the various land uses. Assumptions were necessary to project these land use changes in the CARD model. Of primary importance was information on the potential for conversion of land to cropland. This information was taken from the 1982 NRI, in which land was classified as having low, medium, or high potential for conversion to cropland. These categories were distinguished from each other according to characteristics such as erosion potential. The following assumptions were especially important in projections of land conversion rates using the CARD model.

1. The data source for initial land area was the 1982 National Resources Inventory.

2. Only area in the contiguous 48 states was considered.

3. Only private lands were considered to be eligible for conversion.

4. Forest, pasture, and range lands with potential for croplands are the only major land uses included.

5. Within forest, pasture, and range lands with potential for croplands, only medium and high potential croplands could be converted.

6. There were four categories of potential cropland by producing area: medium potential forest, high potential forest, medium potential pasture/range, and high potential pasture/range.

7. Each acre of potential cropland that entered the model was a composite based on the distribution of potential cropland among the eight Appraisal land groups within each producing area.

8. A composite acre ratio was developed separately for lands with potential for forest and for lands with potential for pasture/range cropland by producing area.

9. Annual rates of conversion to cropland were developed separately for forest land and for pasture/range lands. These conversion rates were developed by CARD Market Region, and there was no distinction between medium and high potential lands.

10. The data used to calculate the rates of conversion were those relating to cropping history in the 1982 NRI.

11. The potential cropland conversion base for the CARD model was 143.2 million acres.

The annual conversion rates from one land use to another available for use in the Second Appraisal are shown in table 10 for the 31 Market Regions in the CARD model. Because of a surplus land situation, no potential land was converted to cropland in the final analysis using the CARD model. Instead, the model retired land through 2030.

In some Market Regions, the annual rates of land conversion discussed previously would result in conversion of large areas of land to cropland after several years into the projection period. Constraints were placed on total land conversion in the CARD model to limit this conversion. Total land conversion allowed between 1982 and 1990 was 80% of the land available and 100% by 2000 if the land would have been needed.

Table 10.—Annual rates of conversion (thousands of acres) from one land use to another and the net effect for the Major agricultural land uses by market regions.[1]

Market region	Pasture range land to cropland	Forest land to cropland	Pasture range land to forest land	Net cropland	Net pasture range land	Net forest land
1	3.50	2.93	2.03	6.43	-5.53	-0.90
2	19.10	-2.17	6.7	16.93	-25.8	8.87
3	48.63	42.37	-9.67	91.00	-38.96	-52.04
4	49.60	42.10	-34.30	91.70	-15.30	-76.40
5	49.80	3.93	-9.13	53.73	-40.67	-13.06
6	64.27	-2.7	-5.03	61.57	-59.24	-2.33
7	34.67	8.17	5.33	42.84	-40.00	-2.84
8	227.27	21.07	-22.43	248.34	-204.84	-43.50
9	112.13	37.30	-34.63	149.43	-77.50	-71.93
10	92.43	22.63	-8.23	15.06	-84.2	-30.86
11	36.83	4.30	-1.40	41.13	-35.43	-5.70
12	157.93	16.47	-9.0	174.4	-148.93	-25.47
13	82.57	27.77	-24.37	11.34	-58.2	-52.14
14	157.77	86.83	-37.57	243.60	-119.2	-124.40
15	278.17	16.10	-33.13	294.27	-245.04	-49.23
16	209.30	0.87	-5.10	210.17	-204.20	-5.97
17	126.97	0.23	-.23	127.20	126.74	-0.46
18	135.47	4.53	-22.53	140.00	-112.94	-27.06
19	80.00	0.70	-20.80	80.70	-59.20	-21.50
20	15.20	0	-3.73	15.20	-11.47	-3.73
28	1.23	0	-22.33	1.23	21.10	-22.33
29	49.73	-8.70	-12.07	41.03	-37.66	3.37
30	62.07	-24.97	-6.70	37.10	-55.37	18.27
31	56.60	7.13	4.47	63.73	-61.07	-2.66

Source: 1982 National Resources Inventory

[1] *Results based on cropping history from the 1982 National Resources Inventory.*

The maximum potential percentage conversion and associated acreages are shown in table 11.

Conversion for Pasture/Rangeland and Forest Land

Projections of areas converted from non-cropland to cropland uses depended in part on conversion costs. Conversion costs used in the 1980 Appraisal were updated and used in the Second Appraisal (table 12). These data were developed on aggregations of Major Land Resource Areas (MLRA's) and then were adjusted to the 10 USDA crop production regions.

Public Grazing Resources

Roughage available on rangeland provides a major source of feed for grazing livestock. In the CARD model, the amount of roughage by area determined the location of the livestock-range industry. The volume of roughage produced on public lands in 1982 was estimated to total about 6.7 million tons. For the purposes of the Second Appraisal, it was assumed that this volume of roughage would be available annually throughout the projection period.

Interest Rates

Two types of interest rates are needed for some analyses done with the CARD model. An interest rate is needed to discount projected costs and returns for long-term investments, such as conservation structures. A short-term interest rate is also needed for analysis of the annual cost of production, such as when farmers borrow money for planting crops. A real interest rate of 4% was used in analysis of long-term investments. This is the same interest rate used by the Forest Service in evaluating long-term investments. The rationale for the 4% rate is discussed in Row et al. (1981). It is especially important that the two Agencies use the same long-term interest rate in evaluating the competition between forests and crops for the same land. A review of interest rates in 1985 and consideration of historical links between long-term and short-term rates were the basis for an assumption of 6.9% for the short-term real interest rate to be used in the CARD model.

Table 11.—Maximum conversion to cropland rate[1] from potential pasture/range land and for potential forest land by market region, percent, and acres, for the years 1990, 2000, and 2030.

Market	Pasture/range land conversion rate						Forest land conversion rate					
	1990	2000	2030	1990	2000	2030	1990	2000	2030	1990	2000	2030
	percent			1,000 acres			percent			1,000 acres		
1	8.6	19.3	100.0	56	126	653	4.1	9.2	100.0	47	105	1,147
2	15.3	34.3	100.0	306	688	2,004	-2.3	-5.1	100.0	-35	-78	1,531
3	50.5	100.0	100.0	778	1,542	1,542	10.1	22.8	100.0	678	1,525	6,685
4	28.4	63.8	100.0	794	1,786	2,798	14.4	32.4	100.0	674	1,516	4,675
5	26.9	60.6	100.0	797	1,793	2,961	6.4	14.4	100.0	63	141	984
6	38.6	87.0	100.0	1,028	2,314	2,661	-2.0	100.0	100.0	-43	-97	2,108
7	42.7	96.0	100.0	555	1,248	1,300	7.9	17.8	100.0	131	294	1,648
8	80.0	100.0	100.0	3,459	4,324	4,324	18.9	42.6	100.0	337	759	1,780
9	45.9	100.0	100.0	1,794	3,911	3,911	12.2	27.5	100.0	597	1,343	4,890
10	52.3	100.0	100.0	1,479	2,826	2,826	15.4	34.6	100.0	362	815	2,352
11	49.5	100.0	100.0	589	1,192	1,192	5.5	12.3	100.0	69	155	1,262
12	80.0	100.0	100.0	2,114	2,642	2,642	45.1	100.0	100.0	264	585	585
13	50.1	100.0	100.0	1,321	2,638	2,638	28.9	65.0	100.0	444	1,000	1,537
14	52.5	100.0	100.0	2,508	4,777	4,777	30.5	68.7	100.0	1,389	3,126	4,548
15	56.0	100.0	100.0	4,451	7,955	7,955	31.4	70.6	100.0	258	580	821
16	39.4	88.6	100.0	3,349	7,535	8,504	57.0	100.0	100.0	14	24	24
17	36.2	81.4	100.0	2,032	4,571	5,614	9.7	21.9	100.0	4	8	38
18	18.0	40.6	100.0	2,168	4,877	12,012	9.8	22.1	100.0	72	163	737
19	19.8	44.6	100.0	1,280	2,880	6,464	5.5	12.3	100.0	11	25	220
20	11.9	26.9	100.0	895	2,013	7,494	0	0	100.0	0	0	0
21	41.0	92.2	100.0	1,400	3,151	3,416	0	0	0	0	0	0
22	74.4	100.0	100.0	2,772	3,724	3,724	80.0	100.0	100.0	4	5	5
23	20.0	45.0	100.0	639	1,437	3,197	-70.7	-100.0	100.0	-8	-12	12
24	17.0	38.2	100.0	69	155	406	-80	-100.0	100.0	-4	-5	5
25	30.7	69.0	100.0	547	1,230	1,783	12.9	29.0	100.0	19	43	149
26	55.2	100.0	100.0	589	1,067	1,067	8.1	18.3	100.0	8	17	92
27	46.5	100.0	100.0	243	523	523	0	0	100.0	0	0	1
28	2.1	4.7	100.0	20	44	934	0	0	100.0	0	0	1
29	35.9	80.9	100.0	796	1,790	2,214	-8.9	-20.1	100.0	-139	-313	1,556
30	80.0	100.0	100.0	950	1,187	1,187	-80.0	-100.0	100.0	-71	-89	89
31	80.0	100.0	100.0	768	960	960	80.0	100.0	100.0	17	21	21
Total	—	—	—	40,542	76,905	103,678	—	—	—	5,159	11,655	39,493

[1]*The conversion rate used was two times the annual rate from the 1982 National Resources Inventory not to exceed 10% per year. Therefore, the maximum change for a Market Region in 1990 would be 80%.*

Note: Potential land available (1,000 acres): Year 1990, 45,701.9; Year 2000, 85,559.9; Year 2030, 143,171.0

Other Assumptions

In addition to the assumptions outlined above, the projections of demands and supplies for the products included in the Forest Service Assessment and Soil Conservation Service Appraisal rest on a variety of other specified and implied assumptions. These are addressed in the appropriate places of the Assessment and Appraisal documents.

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Table 12.—Conversion costs (dollars per acre) for non-cropland to cropland cost by region.

Region[1]	Pasture/range land		Forest land	
	Total cost	Annual cost	Total cost	Annual cost
1	64	4.690	223	16.379
2	127	9.345	223	16.379
3	127	9.345	458	33.694
4	165	12.167	458	33.694
5	165	12.167	458	33.694
6	89	6.552	331	24.334
7	89	6.552	331	24.334
8	127	9.345	458	33.694
9	51	3.744	331	24.334
10	51	3.744	229	16.847

Source: Economics Staff, SCS, 1980 RCA.

[1]*The 10 regions are developed along Producing Area boundaries.*

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Forest Service Regions and Assessment Regions

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-175**

The Evolving Use and Management of the Nation's Forests, Grasslands, Croplands, and Related Resources

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

John Fedkiw

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

The Evolving Use and Management of the Nation's Forests, Grasslands, Croplands, and Related Resources

John Fedkiw

INTRODUCTION

...The lessons of history teach us that no advanced civilization will long survive without due care and continuing stewardship of its renewable soil, water, and plant resources (Lowdermilk 1953).

At the time of European discovery and settlement (16th and 17th centuries) of the area to become the United States, the forests, grasslands, and croplands supported a sparse population of 1–2 million Native Americans (Hodge 1971, Ubelaker and Jantz 1986). The Native Americans used fire in various ways to manage natural resources. It was used universally to hunt wild animals; to encourage fresh, succulent grasses for hunted herbivores; to maintain savannahs such as the Shenandoah Valley; to provide an open forest understory for hunting and travelling; to reduce pest populations; and to develop clearings for farming and various other productive and defensive purposes (Pyne 1982).

Prior to the 16th century, Native Americans had been farming in a crude manner on limited areas for several centuries. They had only hand tools and lacked domesticated animals other than the dog. Cultivated lands were located on the more productive sites and farming included fertilizing with fish, intertillage between plants, irrigation, and land rotation—all familiar practices in the agricultural development of the United States. Partly due to the small number of Indians and their subsistence living style, the forests, grasslands, and cultivated areas were essentially a virgin natural heritage modified only by the widespread use of controlled fires by the Indians and by wildfires (Pyne 1982, Rasmussen 1974).

Today, the same resource area supports the food, fiber, and outdoor recreation and environmental needs for 240 million Americans. In addition, the United States in the past decade has exported 40% of the value of its cropland production, 5% of its livestock production, and 17% of the industrial wood harvest.[1]

Some 57% of the current U.S. crop production, based on farm-level values, consists of plants first domesticated by Indians of the western hemisphere. These crops include maize or corn, the white potato, tobacco, beans, squash, pumpkins, tomatoes, and many more (Rasmussen 1974).

This volume basically reviews the management and use of forests, grasslands, and croplands as our nation developed. It also addresses wildlife, recreation resources, minerals, and water resources. It provides a systematic account of the changing status of our natural renewable resources and minerals and their current status, and concludes with an outlook for the future. The approach is historical and analytical. The viewpoint is largely national. The focus is on land management and use, but policy, population, and technology as well as resource sensitivity, resilience, and productivity are other important dimensions of this review. The roles of economic circumstances, science, and research are addressed. Achievements and problems are discussed as they emerge and an outlook for the future is provided as the review closes.

The reader should note the systematic focus of the methodology of this review is on the resources, their use, and management—who used the resources, what for, and why. The methodology also describes what happened to the resources as well as to the users and the nation. The objective is to provide an integrated view of the use and management of all the renewable resources and minerals. The intent is to present a graphic understanding of the whole development of our resources while describing the parts—the individual resources—in relation to each other and the whole (i.e., the nation).

Forests are lands at least 10% stocked by forest trees of any size, including land that formerly had such tree cover and will be regenerated. Grasslands include pasture and range. Pasture is land used primarily to produce domesticated forage plants for livestock. It includes cropland pasture in rotation, but excludes cropland under winter crops which is grazed and later harvested. Range is land on which the natural plant cover is mainly native grasses, grasslike plants, herbs, and shrubs. Cropland is that land used primarily to produce cultivated crops.

Our present forests, grassland, and croplands constitute 1.63 billion acres or 86% of the contiguous 48 states (U.S. Department of Agriculture 1984a). This compares with an estimate of 1.75 billion acres in 1880 (U.S. Department of Commerce 1975) that suggests a somewhat larger area of forests, grassland, and croplands at the time of colonial settlement. Today's distribution of forests, grassland, and croplands, however, is somewhat different. It includes much former desert that is now irrigated. There is much more cropland and less forest and grassland. Large areas now inundated by reservoirs are excluded as well as areas converted to urban and community use, parks, and wildlife areas, transportation routes, airports, and commercial, industrial, and similar developments. These developed areas, nevertheless, usually have much land that is in tree, grass, or garden cover that is not counted in the forest, grassland, or cropland inventory.

[1] *Sources: U.S. Department of Agriculture, Economic Research Service and Forest Service.*

The ways most of the nation's land is used, the management practices that accompany land uses, and the quality of the related environment are inextricably linked. This narrative account describes how the nation's land and its resources have come to be used as they now are; it also describes the development of their use and management for wilderness and wildlife protection, for recreation, and for parks. This integrated historical perspective is intended to provide a better understanding of the relationships, resilience and renewability, and responsiveness of natural resources to management. It is also intended as a basis for molding a more informed approach to decisions about use and management of natural resources as the nation responds to the future demands of its people and the rest of the world's needs.

CONVERSION OF THE ORIGINAL HERITAGE TO THE NEEDS OF A GROWING POPULATION 1500–1920

COLONIAL SETTLEMENT TO THE REVOLUTION AND INDEPENDENCE, 1500–1783

The European colonists of Eastern North America found an undeveloped, largely virgin land rich with forest, fish, wildlife, grasslands, minerals, and water resources and a vast area available for settlement. It was a land of challenge and opportunity. It contrasted strongly with the situation in England—the home of most of the early colonists.

There land was relatively scarce and increasingly expensive and becoming short of timber. Game and fish belonged largely to the feudal lords. The movement to enclose open-field farms and convert arable land to pasture was underway to capture profits to be gained from sheep and a growing wool trade. Enclosure meant more profitable farming for landlords and freeholders. Common rights of villagers to use certain meadows, woods, and other lands in common were being withdrawn. Small land holders and laborers were facing a declining demand for their services. Land scarcity and rising values were leading to efforts to convert forests, fens, heaths, and marshes to agricultural uses in the 17th century (Rasmussen 1974).

In contrast, the virgin American forests and their wildlife populations, including white-tailed deer, wild turkey, bobcats and cougars, ruffled grouse, black bear, and wolves, extended almost continuously from the East Coast to the prairies of the Midwest. Salmon and shad migrated up the major Atlantic coastal rivers to spawn. The grassland prairies and plains stretched to the foothills of the Rocky Mountains. They were populated with bison and pronghorned antelope, prairie birds, elk, mule deer, wolves, and grizzly bears. The lands beyond the Rockies to the Pacific coast were occupied by the crests of bare mountains at the highest elevations and arid deserts at the lowest. Bighorn sheep were common. The lands between the deserts and mountain tops were covered with evergreen forests and relatively dry grasslands. The great valley of central California was a vast plain and marshland harboring elk, pronghorns, salmon, and grizzly bears. America was a land of natural beauty as well as abundant natural resources (Trefethen 1975).

The American Southwest from central California to Texas and Louisiana was settled by the Spanish from Mexico. They introduced the horse and domesticated cattle to areas that were mostly grasslands, desert, and mountains with some forests. The English and other Europeans who colonized most of the East Coast provided the main thrust of development from the East to the Rocky Mountains and the Pacific Coast.

For the early English colonists, farming under the climatic and geographic conditions of the East Coast was a new experience and challenge. Agriculture developed slowly and served mainly the subsistence needs of the settlers. They often took advantage of lands originally cleared by Indians. As their numbers grew they were compelled to clear forestland by girdling and burning deadened trees, and to farm among the stumps until the latter rotted away. Their farm practices were only a step above those of the Middle Ages, and their tools were not much better. Domesticated animals were initially scarce and expensive to import (Rasmussen 1974). Wild game and fish were a common early source of fresh meat until excessive harvesting decimated their populations (Trefethen 1975). Logs, hewn timbers, and some lumber were the early building materials. Lumber mills were largely water powered and first appeared in Virginia in 1611. By 1700, probably more than 100 mills were sawing lumber. Wood was the universal building material and provided most of the fuel for heating and other purposes (Davis 1983).

The most important minerals in colonial America, aside from stone, clay, and adobe construction materials, were iron and lead. Bog iron was discovered in Virginia and an ironworks operated near Jamestown from 1619 to 1622. The first permanent ironworks was set up in 1643 in Massachusetts. By 1750, iron ore was being mined and furnaces and forages, using charcoal for fuel, were making iron and iron products in all colonies but Georgia. They provided goods for farming and small cottage industries. Lead was used mostly for bullets. Small lead mines were operating in New England and Virginia by 1750, but production was relatively small. Colonial exports of pig and bar iron to England rose in the 18th Century as English production declined to low levels for lack of charcoal (Dorr n.d.).

Water for domestic use was essential and generally received first priority by all concerned. Colonists usually obtained their domestic water needs from a spring, a dug well with a bucket and rope hoist, or a bucket carried from the nearest stream. Location and development of water were seen as the responsibility of each individual, family, or local group or community. Some larger towns used cast iron or wooden pipe systems to distribute water within their communities. Natural lakes, rivers, and wells were used to satisfy the need for water. Waste from domestic water use was usually disposed of in ways that did not jeopardize its continued availability to the users, but not necessarily with regard for its effects on others (Linsley 1979, Schad 1979, Weber 1979).

In addition to sawmills, there were many grist mills with dams and mill races to provide water power. Water wheels also powered machinery in forges and other small industries. Maximum use was made of rivers and harbors for transportation. Their use for transportation during the colonial period required little modification or maintenance. Several canals were built for shipping bulky and heavy commodities. Public interest in improving water resources for transportation emerged about the time of Independence. Meetings, for example, are reported to have been held in 1784 between Maryland and Virginia representatives to consider opening and improving navigation of the Potomac River (Linsley 1979, Schad 1979, Weber 1979).

The settlers gradually improved their tools and farming practices. Subsistence farming remained typical in New England. The middle colonies produced some wheat and other commodities for export. In the South, tobacco became a main export crop reaching 100 million pounds a year by the Revolution. It became a mainstay for the southern plantation system of farming. Rice and indigo, first developed in South Carolina, also became important plantation crops with good export markets by the end of 18th century. Cattle raising and small farms characterized the frontier. It included the back country of New England, the Mohawk Valley, the Great Valley of Pennsylvania, the Shenandoah Valley, and the Southern Piedmont. Settlement west of the Allegheny Mountains was severely restricted when the British Government established the Proclamation Line in 1763, to keep peace with western Indians and protect a prosperous fur trade. No land could be purchased from the Indians, and no settlements established west of the line without permission from the crown. Settlers living beyond the line were directed to leave (Clawson 1964, Rasmussen 1974). There were similar treaties between England and the Indian tribes in the southern Appalachians that also restricted westward migration.

Despite the difficulty of clearing land and farming, colonial farmers were soon producing a surplus for which there was no market in America. The growing population, which exceeded 3 million by the time of the Revolution, placed great pressures on the land. Farming was the main way of making a living and more than 90% of the people lived on farms. The Proclamation Line concentrated that pressure east of the mountains (fig. 1). Restrictions upon land settlement and private conveyance, and trade disputes with England became sources of discontent that helped bring about the Revolution (Rasmussen 1974). By 1776, a 100-mile-wide strip of the East Coast from southern Maine to Georgia had been settled; one-half to three-quarters had been cleared. In the North, 5% to 15% of the land was tilled each year. In the South, 40% to 50% was tilled. Continuous tilling reduced the natural soil fertility. On sloping fields, where plowing up and down the slopes was common, erosion increased and accelerated the loss. Crop yields declined. After several years, some fields lost so much productivity they were abandoned. Abandoned areas sometimes became pastures and, in other cases, reverted to brush and new forests. Land rotation became a regular experience and continues to this day as the economic margins between crop, grassland, and forest use change with demands and technological progress (U.S. Department of Agriculture 1981b). The effects of development were noticed early by George Washington, "Our lands were originally very good, but use and abuse have made them quite otherwise."

During the Revolution the farmers fed the Americans, French and many of the British forces and made money doing so. The farming population also provided most of the revolutionary soldiers. The farmers were a vital key in winning independence and establishing the new nation.

GROWTH AND DISTRIBUTION OF THE PUBLIC DOMAIN, 1783–1920

At the end of the Revolution, the new United States owned all lands as far west as the Mississippi River, except for Florida. The lands west of the original 13 states became the nucleus of the public domain, except for Kentucky, Tennessee and some limited reservations. Although seven of the states had colonial claims to these lands, they were ceded to the new national government with the general understanding that they were won by a common effort of the 13 states and should be common property. Those cessions assured some equity of size and population among the original states. They also comprised a public domain of 268 million acres, about one-half of the area of the national territory of that period. The states also agreed that as the public domain was settled, it would be divided into states that would be admitted to the Union as equals (Hibbard 1924).

The public domain expanded rapidly in the first half of the 19th century. By 1853, the nation's territories included the entire 1.9 billion acres of the contiguous 48 states. More than one-half of this national territory was added to the public domain following the cessions by the original states after the Revolution (fig. 2).

Distribution of the Public Domain

Almost as soon as the new Congress received its first cession of western lands, pressures emerged from numerous interests to fix procedures for disposal of the public domain. "The spirit of immigration is great," Washington wrote in 1784. "People have got impatient and though you cannot stop the road it is yet in your power to mark the way" (Hibbard 1924). The most urgent reasons for early action were:

- to redeem the government promise of land grants to soldiers;
- to secure much needed national revenues from land sales;
- to provide for defense of the Northwest from Indian attacks;
- to link the commercial interest of the western settlements in Kentucky and Tennessee with the eastern states;

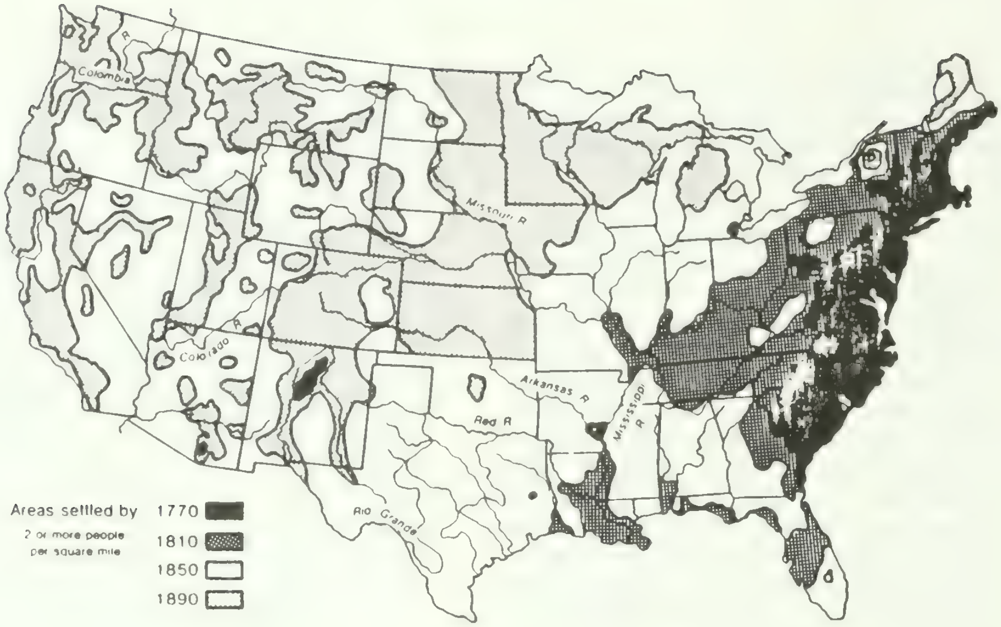

Figure 1.—The progress of settlement in the United States from 1770 to 1890.

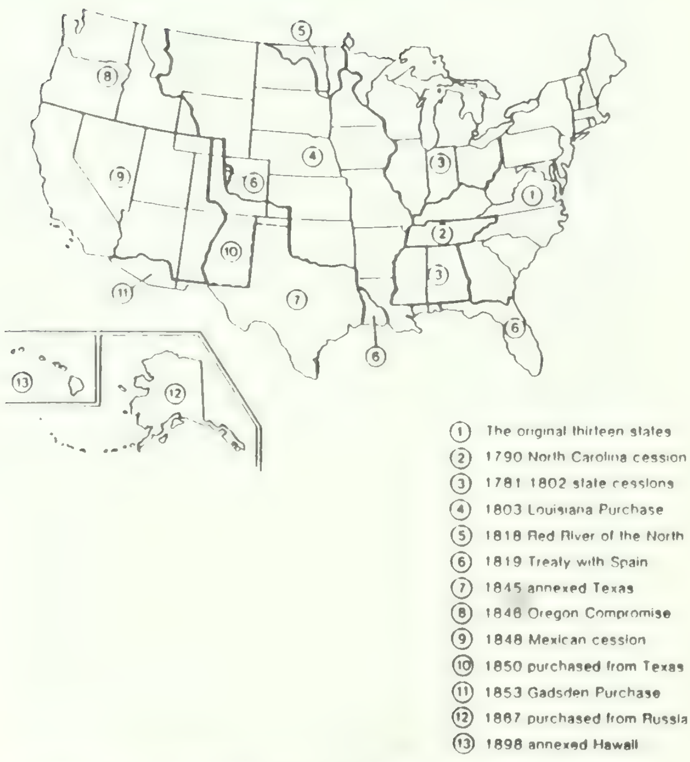

Figure 2.—Acquisition of the territories of the United States.

- to decide upon a form of government for the public domain, including the establishment of new states;
- to dispose of the public domain as property for the public benefit; and
- to respond to the population and economic pressures for immigration to the western lands.

The Northwest Ordinance of 1785 set the basic directions for settlement and development of the public domain (Hibbard 1924). The lands were to be auctioned and sold for cash at a minimum price of $1 per acre. The western lands were to be surveyed into townships made up of 36 sections of 1 square mile, or 640 acres. One-half of the townships were to be sold wholesale. Alternate townships were to be sold by sections. Surveys had to precede sales, but settlement could precede surveys. That became the general practice. One section in each township was reserved for schools and four others for disposition by Congress. One-third of all subsurface gold, silver, lead, and copper deposits were reserved to be sold or otherwise disposed of as directed by Congress (Hibbard 1924, Wilkinson and Anderson 1985). The Secretary of War also was authorized to withdraw one-seventh of the ceded lands for the Continental Army, after which sales could proceed (Hibbard 1924).

The Northwest Ordinance of 1787 provided for the government of the lands as they were settled. It established territories whose settlers would be controlled by officials appointed by Congress. When adult male residents numbered 5,000, a territory could elect a legislature to share power with a council appointed by the governor and Congress. When residents totalled 60,000, the territory could frame a constitution and apply for admission to the Union on equal terms with the original states. A Bill of Rights also guaranteed territorial settlers basic freedoms similar to the Constitution. In this way, the western territories and the states to be formed from the public domain were bound to the nation by the strongest of possible ties—that of equal rights (Hibbard 1924).

There were many debates throughout the 19th century and into the 20th concerning the disposal, management, and use of the public domain, and many laws were passed. However, the main policy thrust into the early 20th century was to transfer land from federal ownership to private individuals, developers, and selected

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...The lessons of history teach us that no advanced civilization will long survive without due care and continuing stewardship of its renewable soil, water, and plant resources (Lowdermilk 1953).

At the time of European discovery and settlement (16th and 17th centuries) of the area to become the United States, the forests, grasslands, and croplands supported a sparse population of 1–2 million Native Americans (Hodge 1971, Ubelaker and Jantz 1986). The Native Americans used fire in various ways to manage natural resources. It was used universally to hunt wild animals; to encourage fresh, succulent grasses for hunted herbivores; to maintain savannahs such as the Shenandoah Valley; to provide an open forest understory for hunting and travelling; to reduce pest populations; and to develop clearings for farming and various other productive and defensive purposes (Pyne 1982).

Prior to the 16th century, Native Americans had been farming in a crude manner on limited areas for several centuries. They had only hand tools and lacked domesticated animals other than the dog. Cultivated lands were located on the more productive sites and farming included fertilizing with fish, intertillage between plants, irrigation, and land rotation—all familiar practices in the agricultural development of the United States. Partly due to the small number of Indians and their subsistence living style, the forests, grasslands, and cultivated areas were essentially a virgin natural heritage modified only by the widespread use of controlled fires by the Indians and by wildfires (Pyne 1982, Rasmussen 1974).

Today, the same resource area supports the food, fiber, and outdoor recreation and environmental needs for 240 million Americans. In addition, the United States in the past decade has exported 40% of the value of its cropland production, 5% of its livestock production, and 17% of the industrial wood harvest.[1]

Some 57% of the current U.S. crop production, based on farm-level values, consists of plants first domesticated by Indians of the western hemisphere. These crops include maize or corn, the white potato, tobacco, beans, squash, pumpkins, tomatoes, and many more (Rasmussen 1974).

This volume basically reviews the management and use of forests, grasslands, and croplands as our nation developed. It also addresses wildlife, recreation resources, minerals, and water resources. It provides a systematic account of the changing status of our natural renewable resources and minerals and their current status, and concludes with an outlook for the future. The approach is historical and analytical. The viewpoint is largely national. The focus is on land management and use, but policy, population, and technology as well as resource sensitivity, resilience, and productivity are other important dimensions of this review. The roles of economic circumstances, science, and research are addressed. Achievements and problems are discussed as they emerge and an outlook for the future is provided as the review closes.

The reader should note the systematic focus of the methodology of this review is on the resources, their use, and management—who used the resources, what for, and why. The methodology also describes what happened to the resources as well as to the users and the nation. The objective is to provide an integrated view of the use and management of all the renewable resources and minerals. The intent is to present a graphic understanding of the whole development of our resources while describing the parts—the individual resources—in relation to each other and the whole (i.e., the nation).

Forests are lands at least 10% stocked by forest trees of any size, including land that formerly had such tree cover and will be regenerated. Grasslands include pasture and range. Pasture is land used primarily to produce domesticated forage plants for livestock. It includes cropland pasture in rotation, but excludes cropland under winter crops which is grazed and later harvested. Range is land on which the natural plant cover is mainly native grasses, grasslike plants, herbs, and shrubs. Cropland is that land used primarily to produce cultivated crops.

Our present forests, grassland, and croplands constitute 1.63 billion acres or 86% of the contiguous 48 states (U.S. Department of Agriculture 1984a). This compares with an estimate of 1.75 billion acres in 1880 (U.S. Department of Commerce 1975) that suggests a somewhat larger area of forests, grassland, and croplands at the time of colonial settlement. Today's distribution of forests, grassland, and croplands, however, is somewhat different. It includes much former desert that is now irrigated. There is much more cropland and less forest and grassland. Large areas now inundated by reservoirs are excluded as well as areas converted to urban and community use, parks, and wildlife areas, transportation routes, airports, and commercial, industrial, and similar developments. These developed areas, nevertheless, usually have much land that is in tree, grass, or garden cover that is not counted in the forest, grassland, or cropland inventory.

[1] *Sources: U.S. Department of Agriculture, Economic Research Service and Forest Service.*

states in this arid region were admitted to the Union, thereby completing the contiguous 48 states. By 1920, the people residing in states formed from the public domain made up 58% of the U.S. population (Carstensen 1968, Gates 1968, Hibbard 1924, U.S. Department of Commerce 1975).

Including state grants, a total of 518 million acres of public land were transferred to private or state ownership between 1862 and 1920. They constituted 52% of the unoccupied public domain in 1862. An additional 272 million acres were set aside as federal reserves for national forests, parks, and other purposes. The remaining unoccupied public land in 1920 was only 200 million acres. Transfer of the public lands to private and state ownership was virtually completed. Today, the remaining unreserved public domain is only about 170 million acres in the contiguous 48 states, and is administered by the USDI Bureau of Land Management.

The number of farms in the United States had grown to 6.4 million by 1920, and 4.2 million (66%) were in the public domain states. In the same period, the farm population rose to more than 31 million, nearly equal to the total U.S. population in 1862 and 30% of the U.S. population in 1920. America was growing fast in all its dimensions during this period (U.S. Department of Commerce 1975).

Historians and later generations have questioned the wisdom and criticized the way the public domain was distributed. Congress clearly believed the vast public domain would be more valuable to the growing nation if it were transferred to the hands of those who could develop it. There was no detailed federal plan for its development prepared by economists, scientists, or anyone else. There was no schedule for the rate of development. The question of food supplies barely entered into the debate, although agriculture was generally seen as the best and dominant use. Food was abundant and cheap, and so were the public lands. The transfer of ownership of the public lands was, and remains, a subject of controversy.

There was much fraud and speculation, which often frustrated the intent of the public land legislation. There were many mistakes in land distribution and use. The General Land Office often asked for more funds and staff but remained taxed just to handle the entry and patenting of the public lands. It never received any real authority to manage any of the public lands in the years leading up to 1920. Public land policy and the distribution of the public domain that went with it were largely the work of Congress. The main guidelines appear to have been that the lands should be settled rapidly, at little or no cost to settlers, and that the new ownership should be predominantly private and widely distributed (Carstensen 1968, Hibbard 1924).

Allen Bogue wrote in 1968 that historians still have good reasons to weigh the consequences of the American land system. "The place of land policy in the broader picture of American economic development is still incompletely understood" (Carstensen 1968). In 1915, Eugene Davenport, then Dean of the College of Agriculture of Illinois, recognized there had been abundant waste and abuse in the distribution and use of public lands, but said, "We have these farms, these cities, these railroads, and this civilization to show for it, and they are worth what they cost" (Carstensen 1968).

PRIVATE DEVELOPMENT AND USE OF PUBLIC LANDS, 1783–1920

Agricultural Expansion to the West

Agriculture expansion to the West responded primarily to rapid population growth. The demands for domestic food supplies, feed for draft animals and domestic livestock, and the opportunity for exports expanded throughout the 19th and the early 20th centuries. Agricultural production was a main source of employment and way of life throughout this period. Agricultural productivity per acre was low and increased only slowly during this period. Therefore, large acreages of farmland were required to meet the nation's growing food, feed, and fiber demands. Declining productivity of the eastern seaboard croplands and the availability of low cost or free public lands for settlement also encouraged expansion to the West. Periods of economic distress and low prices only slowed the expansion periodically. Periods of high demand and prices often accelerated it. Climatic factors frequently brought distress to farmers but did not deter the steady expansion, as long as public lands remained available for easy acquisition and settlement.

1783 to 1860

Agriculture was still very primitive at the end of the 18th century. Probably less than 20 million acres per year were used for cropland.[2] In 1800, this was only 6% of the area of the 17 states of the Union, where essentially all of the population was concentrated at that time (fig. 1). The area cultivated per farm worker probably averaged no more than 10 acres.[3] The harvesting equipment, largely hand tools, determined the number of acres a farmer could cultivate. As the population grew, acres required for food production increased proportionately. By 1860, the total cropland had grown to 109 million acres (table 1). Most of this expansion took place on public lands. Thus, farming entailed continuous clearing of forests, draining of swamplands and valley lowlands, and breaking of prairie sod. The loss of natural fertility and erosion on slopes led to continuous abandonment of some cropland. Abandoned land reverted to

[2]*Based on extrapolation from 1850 and later data on cropland used (table 1) and 1820 and later data on workers (table 2).*

[3]*See note 2.*

Table 1.—Major uses of land, contiguous 48 states, 1850-1982.

Year	Cropland[1]	Grassland pasture and range[2]	Forest land[3]	Other land[4]	Total
		Million acres			
1850	76	([5])	([5])	([5])	1,884
1860	109	([5])	([5])	([5])	1,904
1870	126	([5])	([5])	([5])	1,904
1880	188	935	628	153	1,904
1890	248	892	604	160	1,904
1900	319	831	578	176	1,904
1920	402	750	567	185	1,904
1930	413	708	607	176	1,904
1940	399	723	602	180	1,904
1950	409	700	606	189	1,904
1959	392	696	614	200	1,902[6]
1969	384	689	603	221	1,897[6]
1978	394	661	583	259	1,897[6]
1982	404	659	567	266	1,896[6]

[1]*Excludes cropland used only for pasture.*
[2]*Grassland and other nonforested pasture and range including cropland used only for pasture.*
[3]*Excludes forest land in parks and other special uses.*
[4]*Includes urban areas; rural transportation systems; parks and wildlife areas; defense and industrial uses; miscellaneous uses not inventoried; and area of little surface use such as swamps, bare rock areas, desert, and tundra.*
[5]*Not available.*
[6]*Changes in total area are due to changes in methods and measures used in remeasurement and in surface area of reservoirs.*
Sources: Wooten (1953).

pasture, brush, and regenerating forest. The total lands cleared east of the Mississippi River by 1860 probably totalled between 150 million and 200 million acres. Although there are no reliable estimates for this period, this would have been 30% to 40% of the territory of the United States at the beginning of the 19th century.

The cropland required for domestic food, fiber, and tobacco needs in both 1850 and 1860 averaged about 3 acres per person.[4] There was little improvement in cropland productivity in this period. Rasmussen (1982) also reports there was virtually no improvement in productivity per farm worker. Persons supplied with farm commodities per farm worker, a partial measure for farm worker productivity, remained about the same from 1820 to 1850, and increased 11% from the average of this period to 1860 (table 2). Farm workers made up about 85% of the persons gainfully employed in 1800. This proportion declined to 70% by 1840, and 60% by 1860. The U.S. population remained dominantly agrarian, even though nonagricultural employment was growing much more rapidly (Rasmussen 1974, Taylor et al. 1949).

A breakthrough in farm mechanization took place in the 1830's, when both Cyrus H. McCormick and Obed Hussey invented horse-powered grain reapers. They solved the major problem in wheat production—timely harvesting. However, farmers were slow to adopt the new machines and did so on a widespread scale only during and after the Civil War, when high prices made it profitable.

Plows at the turn of the 19th century were mainly made of wood, and used a minimum of the relatively scarce and expensive iron or steel. Improvements were being made incrementally but slowly. Neither the wooden nor early cast-iron plows would turn the sticky soil of the prairie. More effective one-piece plows made of wrought iron with a steel cutting edge on the share became available after 1837 when John Deere began to produce such plows. Few were sold at first, only 1,000 in 1846 and 10,000 in 1857. Other makers produced similar plows. Sales accelerated as cheaper steel became available in the 1850's. Steel plows effectively cut the prairie sod and worked well at the speed of a working horse. By 1860, some gang plows pulled by horse teams were in use (Schlebecker 1975).

The invention of the cotton gin in 1793 provided an effective way to sort lint from seeds. Cotton culture spread rapidly to the interior of the South and established plantation agriculture throughout the region. Cotton output rose steadily from 10,500 bales in 1793 to 1 million by 1835, and then to 4.5 million by 1861. It strongly commercialized farming in the South, with strong markets

[4]*Based on table 2, total population data and cropland use data from table 1 reduced for exports by 5% in 1850 and 11% in 1860.*

Table 2.—Persons supplied farm products by one farmworker, 1820-1984.

Year	Persons supplied per farm worker: Total	At home	Abroad	Total farm employment[1]	Total U.S. population
			Millions		
1790	—	—	—	—	—
1800	—	—	—	—	—
1810	—	—	—	—	—
1820	4.1	3.8	0.3	2.4	9.6
1830	4.0	3.8	0.2	3.3	12.9
1840	3.9	3.7	0.2	4.4	17.1
1850	4.2	4.0	0.2	5.7	23.3
1860	4.5	4.0	0.5	7.3	31.5
1870	5.1	4.6	0.5	8.0	39.9
1880	5.6	4.5	1.1	10.1	50.3
1890	5.8	4.7	1.1	11.7	63.3
1900	6.9	5.2	1.7	12.8	76.1
1910	7.1	6.1	1.0	13.6	92.4
1920	8.3	6.9	1.4	13.4	106.5
1930	9.8	8.8	1.0	12.5	123.1
1940	10.7	10.3	0.4	11.0	132.1
1950	15.5	13.8	1.7	9.9	151.7
1960	25.8	22.3	3.5	7.1	180.8
1970	47.9	40.6	7.3	4.5	205.1
1980	75.7	52.3	23.4	3.7	227.7
1984	77.3	57.3	20.0	3.5	236.7

[1]*Includes farm operators, unpaid family workers and hired workers.*
Source: Economic Indicators of the Farm Sector: Production and Efficiency Statistics, Statistical Bulletin No. 65, 1979 and Statistical Bulletin No. ECIFS 4-4, 1984, U.S. Department of Agriculture, Economics Research Service.

in New England and England. In Virginia, Maryland, and Kentucky, where cotton did not become established, tobacco remained the staple crop (Hibbard 1924; Rasmussen 1974, 1982).

Farming in the North was characterized by small landowners engaged in general farming. Specialized production such as dairying was growing in New England and the mid-Atlantic states. The Mormons had settled in Utah in 1847 and immediately began irrigated farming. Lowlands and swamplands were being drained largely through the construction of levees by the states enabled by general drainage laws. New machinery had been invented for more farming operations. The use of lime had been demonstrated and commercial fertilizers were available. As westward settlement accelerated in the 1850's, public land sales averaged more than 5 million acres a year. The total population was growing faster than 3% a year (Hibbard 1924). The farm labor force was growing about 2.5% a year (table 2).

1860 to 1920

The Civil War brought on labor shortages. Strong wartime and foreign demands for farm commodities produced high prices. Farmers in the North and West turned to machinery to replace the men joining the armed forces. Strong demands and economic incentives accelerated adoption of new machines and methods during the war, and became the catalyst for the first agricultural revolution in the North and West. In the South, farmers changed little, even though farm workers became scarce. The adoption of new machinery did not accelerate simply because the machines were not available.

By 1880, the area used for cropland totalled 188 million acres. The total persons supplied per farm worker rose to 5.6, almost 25% more than in 1860. The area of cropland cultivated per farm worker rose to 19 acres. The cropland used for domestic consumption remained about 3 acres per person, indicating that average crop yields were not rising significantly. But farm labor productivity was increasing with the growing use of new farm machinery and horsepower. The rate of increase in farm workers from 1860 to 1880 was 1.7% a year. Total population grew 2.4% a year while farm exports rose from 10% of farm production in 1860 to 20% in 1880.

In the South, cotton again dominated the economy. Production, which had dropped to less than 500,000 bales during the Civil War, rose to 6.6 million bales in 1880. Cotton was largely produced by tenants working small acreages under fixed contracts. Cotton was harvested on 16 million acres in 1880.

Nationwide, corn was the largest crop. It made up one-third of the cropland in 1880, when more than 62 million acres were harvested. Wheat was the second largest crop, with 38 million acres harvested in 1880. Hay and oats used another 43 million acres. These crops, including cotton, accounted for 85% of the cropland used in 1880. Close to 40% of all cropland was in row crops. Feed for draft animals and livestock was the dominant use of cropland.

Beginning in the 1880's, dryland farming development was strongly encouraged for the semiarid West. It required half the land to lay fallow each year to gather moisture, so that more acres were needed to achieve efficient production levels. The Northern Pacific Railroad was a strong supporter of dryland farming, and largely through railroad efforts, a Bureau of Dry Land Agriculture was set up in the Department of Agriculture in 1906. Congress tried in various ways to modify the public land legislation to adapt homesteading provisions to the semiarid West. Homestead acreages were increased to encourage irrigation by landowners. Then grants were made to states for resale to raise revenues to develop irrigation. Neither of these irrigation initiatives were effective. By 1920, less than 10 million acres were added to the area that had been irrigated largely by the Mormons in earlier years.

Dry farming did not achieve its expectation. As Schlebecker (1975) expressed it, "the desert never 'blossomed like a rose.'" The early stages of settling in the semiarid lands, conflicts with cattlemen accustomed to an open range, periodic droughts, and low prices in the 1880's and 1890's proved difficult for many farmers and busted some (Rasmussen 1974, Schlebecker 1975).

After 1900, however, dry farming combined with technological advances and economic improvement brought prosperity to the plains and prairies (Rasmussen 1974, Schlebecker 1975). Cultivated cropland continued to expand rapidly after 1880 and more than doubled by 1920 to 402 million acres. In these 40 years more acres were added to the annual cropland used than in the entire 250 years since settlement. Most of these additions occurred west of the Mississippi with large amounts in the dryland areas of the West.

Agricultural expansion from 1880 to 1900 came despite a decline in commodity prices and a generally depressed agricultural economy. The rapid rate of this expansion no doubt contributed to the lower prices. Cropland expansion peaked in the Northeast in the 1880's and net land abandonment was underway. Cropland expansion slowed and peaked in 1920 in the Lake States and Corn Belt, except for Illinois, Iowa, and Wisconsin. Cropland also peaked in 1920 in the South, except for North Carolina, Florida, and the Delta States.

Total farm output almost doubled between 1860 and 1920. The abundance of production and low prices in the 1880's and 1890's attracted European buyers who easily absorbed 20% or more of the annual crop production. After 1900, farm prices rose again and reached very high levels as World War I reduced European production and increased demands on U.S. cropland. Crop exports averaged more than 25% of U.S. production in the years 1900 to 1920 (U.S. Department of Commerce 1975). Farm income and prices after 1900 held steady in comparison to the rest of the economy, until the early 1920's (Rasmussen 1974). It was a prosperous time for farmers.

Agricultural productivity, measured as the ratio of total outputs to total inputs, increased about 50% between 1860 and 1920 (U.S. Department of Agriculture 1980b). Farm population reached its historic peak of 32 million

in 1910, as did the number of farm workers at 13.6 million. The average cropland cultivated per farm worker rose to 30 acres, 60% more than 1880; persons supplied per farm worker rose to 8.3, 48% greater than 1880. Cropland used to supply domestic food and fiber needs remained at 3 acres per capita, indicating little general improvement in average crop yield and livestock productivity. The productivity gains came largely from reduced farm labor and costs of production associated with new and improved farm machinery and equipment. Even these improvements were limited by almost complete dependence on horsepower. Tractors numbered fewer than 250,000 and there were even fewer trucks. Horses on farms in 1920 totalled 20 million, just a million less than the World War I peak of 21 million. Farm workers actually declined 1.5% from 1910 to 1920, releasing farm labor resources for the first time for use in the rest of the national economy as total population and total demands continued to grow.

The Conversion and Use of the Forests, 1800–1920

At the time of settlement, the original forests of the contiguous 48 states covered about 850 million acres. By 1920, they had been reduced to 567 million acres, about the same as today (table 1). Thus, a net area of 250 million acres was cleared for farming and other uses or allocated to national parks, wildlife refuges, or other purposes. The most rapid clearing occurred between 1800 and 1920. Because some farmland was abandoned and left to revert to forest during this 120-year period, the gross area cleared was somewhat more than the net change in forest area. Most of the clearing as well as the forest regrowth occurred east of the Mississippi.

The standing commercial sawtimber in 1800 is estimated to have been 7.5 trillion board feet. Most of it was old growth timber up to several hundred years old. (Today's managed forests seldom have rotations as old as 100 years.) By 1920, this virgin inventory was reduced by almost 75% to about 2.0 trillion board feet and was still declining. About half the conversion occurred on lands cleared for farms and other purposes, usually but not always on the more productive soils. The other half was harvested from lands that remained in forest use and were left to regenerate as young growing forests.

The net growth of forest growing stock, which includes commercial tree species down to 5 inches in diameter, is considered to have increased from zero in 1800 to about 5 billion cubic feet by 1920 (Davis 1983). The zero growth for 1800 is based on the assumption that annual mortality equals or exceeds annual growth in old growth, biologically mature, and overmature forests. (For comparison, the growing stock net growth in 1976 was estimated to be nearly 22 billion cubic feet, about 50% more than the actual 1976 harvest.)

The net clearing of forests for farms continued at a declining rate in most of the Northeastern States until 1880, and until the 1920's for the rest of the states east of the Appalachians. On public lands west of the Appalachians, clearing accelerated after 1800 with the expanding westward migration, and did not peak until after the 1920's.

Farm Woodlands

Most farms east of the prairies and plains retained woodlands on their poorer lands. In 1860, farm woodlands totalled 244 million acres, about 120 acres per farm. The typical farm woodland in the more developed areas, however, was closer to 50 acres. At the frontiers, it commonly exceeded 100 acres. In 1920, the total farm woodland area was reduced to 168 million acres—about 25 acres per farm, including many farms on the plains and prairies with much less or none (Lane 1959, U.S. Department of Commerce 1975). Woodland provided farmers the materials needed for housing, farm buildings, fences, fuel, forage, and many other needs. In 1853, for example, there were more than 3 million miles of farm fences built with wood and they had to be replaced about every 25 years (Davis 1983).

Firewood

The common use of wood was for heating, cooking, and energy for steam engines, steamboats, railroads, and growing industrial purposes. Fuelwood was initially abundant and cheap in the forested areas east of the prairies. It became increasingly scarce and costly in the more populated areas, as lands were progressively cleared for farming and for sale of fuelwood supplies to urban dwellers. By 1840, farmers were selling 5 million cords of firewood annually (Davis 1983). In 1853, a 76-mile New York Central rail line had 18 wood storage stations along its tracks to supply its needs. Firewood provided 95% of the BTU's produced in 1850. The fireplace was the main heating facility in 1800 and required 10 to 20 acres of woodland to supply its wood needs. Wood stoves, introduced in the late 18th century, gradually replaced fireplaces because they were more efficient; improving wood stoves became the main means for increasing fuel efficiency. From 1793 to 1840, the U.S. Patent Office issued more than 800 stove patents, more than for any other object (Davis 1983).

Firewood use peaked in the 1870's. The wood share of BTU's dropped to 73% as the use of coal increased. By 1920, wood provided less than 10% of the BTU's. Most of the wood users were farm families.

Lumbering

Throughout the 19th century lumber was the universal building material. The demand seemed virtually insatiable even though lumber prices in real terms rose steadily and continuously. Enormous wood supplies were needed to construct homes and all types of private and public buildings in the expanding cities of the East and the growing towns and farms on the prairies and plains. The supply was considered unlimited. There always were new virgin areas of timber to which to turn.

Up to 1845, it is probable that most of the saw logs used for lumber and larger timbers came from farm-owned

woodlands that were being progressively cleared for farming (Lane 1959). Expansion of cotton plantations in Georgia, for example, had pushed back the forests to the mountains in the extreme northwest of the State by the 1840's (Davis 1983).

Logs were heavy and difficult to transport. Sawmill productivity was low, only 3,000 to 5,000 board feet a day. As a result, there were many sawmills in every state. New York had 7,000 mills in its 74 counties. Vermont, with one-fifth the land area, had 1,000-plus mills (Lane 1959). Distribution and marketing were largely limited to local watersheds. Commercial shipments across regions were limited mainly to white pine. Southern states were exporting some southern pine. Georgia with the largest lumber industry, exported about 25 million board feet a year in the 1840's; about half of it went to the West Indies (Davis 1983). Reported lumber production increased from an estimated 300 million board feet in 1799 to 1.6 billion by 1839. The real price of lumber rose 2.5 times or 2.3% a year (Steer 1948, Ulrich 1985), indicating that user demands were growing faster than supplies.

Improvements in saws and power sources between 1840 and 1860 made it possible to build mills to produce 40,000 board feet a day. As larger mills were built, the number of small sawmills declined sharply, even though total lumber production expanded rapidly (Lane 1959). The development of the crosscut saw for tree felling also increased labor productivity. Previously, all felling had been done with hand axes. The extension of the rail system, often through areas passed by or still unsettled, and the development of railroads as an alternate to dependence on streams for log-rafting, allowed lumbermen to open up vast new areas and timber stands that had been inaccessible earlier. These developments, together with rising lumber demands and prices, led to continued growth and migration of the lumber industry. By 1920, it had expanded to all the major timber regions of the nation.

Lumber production accelerated in each successive decade after 1839 to 1889, except for the Civil War decade (table 3). The expansion continued until 1906 and 1907 when the output of the lumber industry reached its historic peak of 46 billion board feet. Per capita lumber consumption rose from 250 board feet in the 1840's and 1850's to a peak of 530 board feet in 1906 and 1907, despite steadily rising real prices (table 3). To meet these needs, vast areas of virgin softwood and hardwood timber were harvested in all parts of the East, and major logging initiatives were underway in the West.

New York succeeded Maine as the leading lumbering state in 1839. In 1860, Pennsylvania became the lead producer. In 1870, Michigan took the lead, and by 1879, Lake states production exceeded that of the Northeast. A decade later Lake states lumber output reached its peak at 10 billion board feet, 37% of the estimated national supply. The white pine of the North remained the dominant softwood construction species throughout the 19th century. In 1899, lumber output in the South rose above 11 billion board feet as Lake states output declined.

By 1910, the southern production was 20 billion board feet, 44% of the national supply. Thereafter, it declined and was again at 11 billion feet in 1920. As Lake states production declined after 1900, Midwest lumbermen increasingly shifted their operations to the West Coast. They competed strongly with the southern producers for the markets of the Midwest, and by 1920 were producing about 10 billion board feet. Rocky Mountain production remained below 2 billion feet (Davis 1983).

The successive declines in state and regional lumber outputs meant that the virgin volumes of white pine timber and then southern pine were being exhausted. Little or no provision, other than unassisted natural regeneration, was made for the regrowth of harvested stands. There were no foresters in America until the late 19th century. Even so, the regrowth would have taken 60 or more years to mature and become competitive with the virgin old growth. Bernard Fernow, a German forester employed as the chief forester with the U.S. Department of Agriculture, reported in 1892 that forest owners failed to practice forest conservation because it did not pay. The costs of management showed that the profitable harvest of timber and conservation "are at present more or less incompatible" (Robbins 1985). A veteran editor of the American Lumberman, J.E. Defebaugh, expressed a similar view to the American Forestry Association in 1893: "...little can be expected from the lumberman or timber owner who depends on that business for his livelihood in...conserving the forests, simply because it does not pay him" (Robbins 1985). Gifford Pinchot on a later occasion told a lumberman's meeting that it would be fruitless to discuss forestry unless it was profitable: "We must show first that forestry will pay" (Robbins 1985). In general, the fixed costs of interest on loans and bonds for standing timber as well as annual taxes on the timber and land offered little incentive to lumbermen to hold old growth or mature timber for many decades. The risks of loss from fire and

Table 3.—Total lumber production and the relative producer price index[1] for lumber, 1799–1983 (1967 = 100).

Year	Lumber production[2] bill. bd-ft	Price index	Year	Lumber production[3] bill. bd-ft	Price index
1799	0.3	NA	1910	44.5	34.4
1800	NA	6.4	1920	35.0	53.8
1809	0.4	7.0	1930	29.4	48.2
1819	0.6	8.6	1940	31.2	63.7
1829	0.9	11.4	1950	38.0	105.9
1839	1.6	14.6	1960	32.9	97.0
1849	5.4	18.1	1970	34.7	103.0
1859	8.0	20.5	1972	37.7	133.8
1869	12.8	21.8	1974	34.6	129.4
1879	18.1	25.5	1976	37.0	127.3
1889	27.0	29.6	1978	40.5	154.0
1899	35.1	33.3	1980	35.4	121.2
			1982	30.0	103.8
			1984	36.9	112.7

[1]*Actual price index divided by all commodities price index.*
[2]*Source: Steer (1948), Ulrich (1985).*
[3]*Source: Ulrich (1985).*

the annual costs of taxes and protection of young stands for long periods discouraged investment in forest management. Thus, the old growth heritage remained the only physical and economical source of softwood construction lumber throughout the period of rapid settlement and development of the new nation, and wood remained the primary building material.

Cutover Lands, Forest Fire, and Land Use

The term "cutover lands" came into use in the 1880's and 1890's, particularly in the Lake states where lumbermen harvested the pine first and later returned to cut the commercial hemlock and hardwoods. Similar cutovers occurred in parts of the Northeast and the South as lumbering cleared extensive timber stands in largely unsettled areas. Although efforts were made to settle these lands, they remained unattractive to most farmers. The pine stumps did not rot and had to be grubbed or blasted out.

The soils in the pine cutovers of the Lake States and South were usually sandy and had low productivity for farming. There were few other resources of value. Mill towns that grew up with the lumber industry declined rapidly and often disappeared as the timber ran out. The prairies offered more productive alternatives for most settlers and had no stumps. Settlement of the cutover areas for farming never really became successful or thrived. Those who tried it usually faced a dismal future in later years. By the 1920's, 156 million acres had been logged in the South. In the Lake states and Northeast, the acreage was less—perhaps about one-half as much (Davis 1983).

Farm Woodland Grazing

Farm woodlands and the frontier forests were used for grazing from the time of first settlement. Competition from domestic animals forced game animals away from the settlements. Acorns and beechnuts in the hardwood forests supported hog raising and helped make pork the leading domestic meat staple for American families by the time settlement reached the Mississippi River. "Cow pens" on the cutovers of the South became an early base for a cattle raising empire. Sheep herding followed crop farming in New England as farmers migrated to the more productive, very cheap or free lands of the public domain (Davis 1983). Browsing by dairy cattle also expanded in the North as dairy production grew (U.S. Department of Agriculture 1958).

Census data show that 80 to 90 million acres, or about one-half of the farm woodlands were being grazed between 1900 and 1920. That relationship suggests that woodland grazing may have been somewhat greater in the early 19th century, before land clearing had reached its peak level.

Livestock in some areas of the North injured and destroyed young trees by browsing and trampling. Excessive use often accelerated erosion on woodland slopes and sometimes compacted soils, reducing soil quality and forest productivity. In the South, hogs rooted pine seedlings to feed on their roots and prevented thousands of acres from regenerating (U.S. Department of Agriculture 1958). Regular woodland burning became common practice—an effective way to reduce the rough; encourage the growth of palatable grasses, legumes, and other herbaceous vegetation for livestock; keep down the snakes, ticks, and chiggers; and aid the movement of cattle. It was an art learned from the Indians and sustained by the settlers throughout the 19th century. Older southern pine trees were resistant to light fires, but the reproduction was usually destroyed. Burning cutovers for grazing and the rooting of hogs delayed their regeneration.

Forest Fires and Other Catastrophic Timber Destruction

Forest fires were common and often burned unchecked. They repeatedly burned over the residual brush and second growth forests. Ely and Wehrwein (1940) reported "the cutover fires were regarded lightly because they were considered a help to the land-clearing settler. However, they destroyed the humus of the soil and the seeds of young trees which might have yielded a second harvest even without the care of man."

Forest fires were the most conspicuous catastrophic events that damaged the forests in the 19th and early 20th centuries, particularly in the North and West. In the South the rural sentiment was "unqualifiedly in favor of the annual burning over of the pineries" (Pyne 1982). Regular burning precluded the buildup of forest fuels that encouraged episodic fires elsewhere. Thus, southern forests, unlike those of the North and West, remained free of catastrophic fires until the 1930's (Pyne 1982).

The first holocausts of record were the Miramichi and Piscataquis fires of 1825 which burned 3 million acres in Maine and New Brunswick, Canada, the centers of lumbering at that time. In 1871, the Peshtigo fire burned 1.3 million acres in Wisconsin and took 1,400 lives. At the same time Chicago was burned with a much lower loss of life. Other fires burned 2.5 million acres in Michigan. In 1881 and 1894, fires again burned several million acres in the Lake states. Large fires also recurred in 1908, 1911, and 1918. In the Northeast, fires burned more than 1 million acres in an arc from Maine to upstate New York in 1903 and recurred in 1908. In the West in 1902, more than 110 large fires, sometimes referred to as the Yacolt fire, burned more than 1 million acres and took 38 lives in western Oregon and Washington. These fires led to the formation of private fire protection organizations which merged under the Western Forestry and Conservation Association in 1909. The catastrophic 1910 fire in northern Idaho and northwestern Montana had the greatest effect on the development of federal policy for forest protection from wildfires (Davis 1983, U.S. Department of Agriculture 1958).

These and many other episodic fires elevated concerns about timber famine and damage to watersheds. Industries organized their own fire protection associations where they owned valuable timber. There also were systematic public efforts, particularly at state and regional

levels, to establish fire protection systems. Total timber losses from catastrophic fires were reported to be 20 billion board feet from 1900 to 1920, a small fraction of the consumption in this period (U.S. Department of Agriculture 1958).

Catastrophic losses from insects and disease were greater. They approached 30 billion board feet and included the losses from the spruce bud worm in New England and the Lake states, the mountain pine beetle in the West, and chestnut blight in the Northern States. Total catastrophic losses from 1900 to 1920 were about 50 billion board feet. About 15% of the losses were salvaged (U.S. Department of Agriculture 1958). Except for the local cost of fire fighting, loss of life, and damage to developed properties, these losses probably were not felt by the general economy. The threat of these destructive forces to the future, however, was real.

Grasslands and Grazing

Cattle and sheep were introduced in the colonial period and were raised on the frontier woodlands and developed pastures. Cattle raising became important early on the Southern Piedmont. But it was transitory, giving way to cotton plantations and crop production as farm settlement moved westward (Rasmussen 1974).

In the early 19th century, European visitors described the cattle as generally red in color and indifferent in size and quality. Longhorns and a variety of Shorthorns were being imported from England to Virginia and Maryland in 1783. In 1817, they were being introduced into Kentucky together with Herefords. Improved Shorthorns were also being imported to Pennsylvania in 1822, and Ohio herders were importing Durham cattle in 1833 (Rasmussen 1974).

Cattle raising and hogs were largely a frontier industry. Drovers trailed herds of both from the Ohio country to the East from 1818 to 1845. Dairy cows became important in New England and the mid-Atlantic states. Some farmers in the latter states were fattening cattle for the city markets. In the Old South, as cattle gave way to cotton, its livestock declined from 22% of the national total in 1840 to 13% in 1860 (Rasmussen 1974).

The Census reports that all cattle numbered 58.6 million in 1867. Dairy cows made up 30% of that number. Pasture land appears to have been equal to about 60% of the cropland, 40 to 60 million acres. Pastured woodlands seem to have been in the 80 to 100 million acre range. Pastures were probably utilized mainly for dairy cows and draft animals, and some beef cattle and sheep.[5]

By 1865, the cattle industry had moved to Illinois, Iowa, and Missouri and then to the West Coast (Rasmussen 1974). Cattle herds were introduced by Spanish herdsmen in both Texas and California. American settlers continued the industry and improved the stock by breeding. Herds roamed freely on the Plains with little tending. Herding was the predominant way of raising beef cattle. Markets were remote, and cattlemen had little incentive to produce quality beef. Some cattle were sold in Texas, but more in New Orleans. In 1846, Texas herders even drove 1,000 head to the Ohio Valley. During the Civil War, the Texas herds were largely neglected but multiplied anyway, and by 1865, 5 million head grazed the Texas rangelands. Various entrepreneurs rounded up these herds (they had no owners) and, in 1866, began the first drive to northern markets in Missouri. In 1867, cattle were herded to the Abilene, Kansas, rail head (Schlebecker 1963).

Cattle herding was permitted on the public lands throughout the 19th century without constraint. The open and free range provided a strong economic incentive for cattlemen to use the abundant grasslands of the Western Plains. The acquisition and purchase of large ranch holdings did not get underway on a significant scale until the late 19th and early 20th centuries.

In the 1870's and 1880's, cattle herding expanded throughout the Northern Plains. However, as barbed wire became cheap, cattlemen began to substitute fences for cowboys on lands they were accustomed to graze with herdsmen. Some companies fenced as much as 1 million acres each and ranches of 100,000 fenced acres were common. Settlers entering the Plains in the early 1880's complained of hundreds of miles of fencing on public lands suitable for farming. In 1885, Congress passed a law making fencing a punishable offense. By 1890, the fencing was removed and grazing returned to free use and open range herding. Most of the range was in full use by domestic livestock. As homesteading rapidly progressed, cattlemen were pressed to forcefully resist homesteaders who fenced off the better parts of the public lands (Hibbard 1924, Schlebecker 1963).

There was no systematic or orderly control of the use of the open range. No agency had any management responsibility to avoid overgrazing and the damage to the forage that followed. The vacant public range lands were free to all users until they were homesteaded or sold. Total stock cattle numbers rose from 21 million in 1870 to 45 million in 1890. Stock sheep in the nation rose from 36 million in 1870 to 50 million in 1884 and 1885. Their numbers remained between 40 and 47 million to 1910 (U.S. Department of Commerce 1975).

Cattlemen tried to control the range by forming their own user associations and by purchasing limited base areas of meadow land and sources of water. The coming of sheepmen intensified competition for the free range. Sheepmen also sought out the key watering places and purchased parts of railroad grants as base property. Various grazing interests parcelled out large parts of the open range through informal agreements and compacts. The agreements, however, did not control access. Notorious sheep and cattle wars emerged (Davis 1983, Schlebecker 1963).

Herding on the open range often suffered from severe winters. The ultimate blizzards came in the winters of 1886 and 1887. Cattlemen lost 30% to 80% of their cattle on the Northern Plains. Many turned to ranching and acquired base properties to provide for winter feeding.

[5]Estimates extrapolated from data reported for 1867 and later years from U.S. Department of Commerce (1975).

The adjustment was needed to meet the periodic catastrophic conditions imposed by an unpredictable climate, to work out a dependable system of meat production, and to contend with the homesteading of the public lands by farmers. Settlement by farmers remained the basic objective of the nation and Congress, despite the great uncertainties of farming in the semiarid areas of the West (Schlebecker 1963).

The changing organization of grazing did not alter the free use of the open range. The Public Land Commission in 1904 reported overgrazing and ruin of millions of acres of valuable grazing lands because of lack of control. Range vegetation was so seriously reduced in some areas that it induced soil erosion. Stockmen knew and understood the problem. But they had no economic incentive to improve or invest in managing the free range to protect or restore productivity without an assured means of profit. A Public Land Commission had suggested in 1880 that range land be disposed of in huge blocks of 2,560 acres. In 1905, the Commission proposed grazing districts and leasing. Both initiatives failed (Davis 1983, Hibbard 1924).

Several special homestead acts were passed between 1904 and 1916 to encourage transfer of the grazing lands to private ownership. Although the most knowledgeable persons believed the acreages should be at least 2,560 acres or more than 1,000 acres, the largest homestead grants for stock raising were limited to 640 acres. About 100 million acres were transferred to private ownership in this period. Most likely, they were the better lands of the declining area of the public lands which remained available for grazing as open range (Cartensen 1968, Hibbard 1924, U.S. Department of Commerce 1975).

On the forest reserves, created by Presidential Proclamation in 1891, grazing was allowed under a permit system. The area was only 17 million acres in 1891; an additional 21 million acres were proclaimed in 1897. At first, however, it was believed the reserves precluded grazing. That became the initial policy though it was ineffective. Protests of stockmen who did not feel grazing damaged the forests led to the permit system. The Forest Management Act of June 4, 1897 (Stat. 30, 34–36) authorized the management of the reserves to improve and protect the forest, secure favorable conditions of water flow, and furnish a continuous supply of timber. The General Land Office, in 1900, published rules and regulations for issuing permits based on the number of animals the forested range could support consistent with the welfare of both the forest and the cattle. The stockmen accepted the permit system, and in 1905, when the reserves were transferred to the Forest Service for management, grazing fees were introduced. The stockmen objected to the fees for a while. However, the stock fared better under the government restrictions and the permittees soon recognized this advantage as well as the assurance of the grazing privilege (Hibbard 1924, Roth n.d.).

The forest reserves were renamed national forests, and by 1920 their total net area exceeded 150 million acres. In 1915, the Secretary of Agriculture, reporting on the grazing of the forests, stated, "When the regulated system was established the forest ranges, like the open public lands today, rapidly were being impaired. The productivity of the land for forage in most places has been restored and everywhere is increasing; the industry has been made more stable; stock come from the forest in better condition...that the forests have promoted the development of the stock industry...is appreciated by the stockmen and they are urging that a similar system of range regulation be extended to the unreserved public lands" (Hibbard 1924, Roth n.d.). The forested range lands were at the higher elevations, where the climate was generally cooler and moister. For this reason, these lands were probably less damaged than the open range grasslands at the lower elevations with much dryer conditions. They probably responded more effectively to good management for the same reason.

During World War I, beef demand and prices rose sharply. Total stock cattle rose more than 25%, from 40 million to 52 million between 1910 and 1918. The ranges and pastures became more crowded. Stocking levels were increased on all lands. Cattle and sheep numbers on the public ranges—the national forests and the unoccupied public lands—increased sharply, despite the fact that they were still suffering from the impacts of long-term overgrazing. Droughts aggravated the impacts of higher stocking levels. The end of the war drove livestock prices and profits down, and the livestock industry into hard times. As a result, federal land managers were forced to slow down their efforts to reduce range stocking, and thus, the effects of continued overgrazing were extended into the next several decades.

Wildlife and Fisheries in the 1800's

The original fauna of the country included salmon running up the major coastal rivers, elk, and bison in Pennsylvania and Kentucky and across the undisturbed Plains, enormous flocks of passenger pigeons in the old growth hardwood forests of the East and Midwest, wolves and mountain lions in virtually every state, and grizzly bears throughout the Plains and West. Wild turkeys were abundant in the South. Deer were common but probably not abundant. Native Americans used these wildlife and fish for food, fiber, and religious purposes but had only minor local impacts on their populations. Agricultural development, logging, domestic livestock grazing, industrial and urban pollution of waters, heavy harvest of game, and the spatial requirements of the growing population of new settlers and their settlements progressively changed the more or less stable, natural situation for wildlife and fish.

Wildlife and fish populations are inextricably linked to their habitats and change as their habitats change. Severe winters, prolonged drought, diseases, and heavy predator control also influence the location and size of populations.

The conversion of the original eastern forests together with subsistence hunting and efforts to eliminate predators of domestic livestock exterminated wolves and lions from much of the East and Midwest and eliminated

deer, elk, turkeys, and passenger pigeons from many eastern areas. Many nongame birds of the eastern forests also declined. These losses were offset by a boom in farm wildlife. The new habitats that replaced the old growth forests were excellent for rabbits and quail.

Growing industries and urban communities increasingly dumped their wastes into rivers and bays causing declines in salmon runs and resident fisheries. Market hunting decimated many wildlife populations and accelerated the effects of habitat changes that brought the passenger pigeon to extinction. Venison, wild fowl, and other game were staple foods in most American homes throughout the 1800's. Deer haunches and quarters of beef hung together in butcher shops. Prices for braces of ducks, snipe, woodcock, and passenger pigeons were regularly quoted on the financial pages of New York, Boston, and Chicago newspapers (Trefethen 1975).

Settlement across the prairies and plains to the West pushed the bison, elk, wolf, grizzly bear, bighorn sheep, and pronghorn antelope from their original haunts and to critically low population levels. Professional hunters reduced the millions of bison to a few scattered remnant herds by the end of the 1880's. The accelerated slaughter began largely after the Civil War with arrival of the railroads on the prairies and plains, and the need to feed construction workers. The railroads also provided reliable and rapid means to ship bison meat products to the eastern markets. Although there was some public sentiment for preserving some sample bison herds, it was overwhelmed by strategic considerations for the assured orderly settlement of the West and reduction of Plains Indian resistance which depended upon the bison herds. The enormous pressures for settlement, farming, and domestic livestock grazing also left no place for the bison. To save one herd in its natural state would have taken a contiguous area the size of Montana; but no such area remained after 1880 (Trefethen 1975).

Five factors contributed to the steady reduction of the wildlife populations throughout the country in the 19th century: the axe, the cow, the plow, the gun, and hard winters. The deeper, underlying influences were the rapid growth of the American population and its food, fiber, and timber demands, the demand for the cheap or free public lands, the dominant agrarian way of life, good markets for game and wild fowl for food, and the lack of generally effective state or federal constraints on the control of predators or on hunting and taking of wildlife and fish (Trefethen 1975).

Mining Laws for Public and Private Lands

In the 19th Century, the mining of private lands and those owned by state and local governments, including more than 1 billion acres alienated from the public domain, were governed then as today by state laws. They had their origins in the mining laws of the original 13 colonies and England. Mineral rights in general go with the land together with surface rights, water rights, and timber rights. Owners may lease their lands for mining in return for a royalty or other payment form, or sell the land or just the mineral rights separately. This system of state mining law applied to Texas, which joined the Union in 1845 and retained its public lands, to individual land grants made by the Spanish territorial governments in the Southwestern States, and to 44 million acres of public domain assigned to native corporations in Alaska by act of Congress in 1971 (Wilkinson and Anderson 1985).

Congress revised and consolidated the federal mining statutes of 1866 and 1870 under the General Mining Law of 1872. It remains the basic law, as amended, for hard rock mining on public domain lands today.

The 1872 Act provided that public land be open to prospecting unless withdrawn by the President or Congress. Any U.S. citizen or corporation or an individual with declared citizenship intentions could enter public lands and stake a claim upon discovery of a valuable lode or placer deposit covering up to about 20 acres of overlying lands. Any number of claims could be staked as long as each included a "discovery." The unpatented right gave miners "the exclusive right of possession and enjoyment of all the surface" within the claim bounds. Claims could be held indefinitely, as long as some minimum assessment work was done on each claim each year. Miners also had the right to remove minerals without payments to the government and the option of buying the land for a nominal price and receiving a patent in fee upon validation of a valuable mineral discovery.

This liberal law was consistent with the federal policy for opening the West and encouraging settlement as well as with miners' determination that prospecting and mining be left to local rather than federal control. The law was clearly designed for the individual prospector to assure him the rewards of his discoveries. For decades, it became the Interior Department's position that it had no authority to regulate mining or miners and that the Department could do little but issue patents (Cameron 1986, Dorr n.d., Wilkinson and Anderson 1985).

Under the 1872 Act, claims did not have to be recorded with any federal agency. For many years there were no government records of the number or status of claims on public lands. Claims eventually numbered in the millions. Many were staked and sometimes patented to acquire the land for various nonmining purposes such as grazing or recreation. Enforcement of claim requirements were often lax. Assessment work, for example, was never done on many claims. Unless patented, claim boundaries often were not accurately surveyed and locations not tied in exactly with official land surveys. Other frequent difficulties were vague claim notices, overlapping claims, and lost corner stakes. Litigation was the result in many cases (Cameron 1986).

Minerals Development, 1800–1870

From the Revolutionary Period through the Civil War, the principal metals used in the United States were iron, lead, copper, gold, and silver. Westward exploration and settlement led to the discovery of new ore deposits.

Congress provided that the reserved lead-bearing lands should be leased. But administration proved difficult. Beginning in 1829, lead lands and then copper lands were gradually sold. Iron and coal lands were ruled as non-mineral lands. Prices for mineral lands were generally higher than for farmlands. But many such lands were not classified, and fraudulent acquisition was not uncommon.

The Lake Superior iron ores, from which most of the domestic iron production has come, were discovered in 1845. Improved transportation, especially the canals, facilitated shipment of iron ore from the Lake Superior area to the coal-producing regions of Pennsylvania and midwestern states. The development of the steam engine and railroads after 1830 brought an increase in demand for iron. Large scale iron production gradually replaced local ironworks. Pig iron output from anthracite blast furnaces rose from 22,000 tons in 1842 to 393,000 tons in 1856 (Dorr n.d.).

Lead deposits were found in a number of places—southern Missouri, the tri-state area in Missouri, Oklahoma, and Kansas; eastern Tennessee; and the Wisconsin-Illinois area. Copper was discovered in Upper Michigan in the 1840's. The petroleum industry began in Pennsylvania in the late 1850's (Dorr n.d.).

During the first three-quarters of the 19th Century, most of the extensive mineral resources in the eastern United States passed into private ownership under the various laws providing for agricultural settlement and development. That included lead and zinc land in Missouri and Wisconsin, copper mines in Michigan, extensive coal lands in the western slopes of the Appalachian Mountains, and a large share of the iron deposits in Alabama, Michigan, Wisconsin, and Minnesota (Hibbard 1924).

The discovery of gold in California in 1848 led to the location and development of one major mining district after another in the Western States. Silver-ore mining began in Nevada in 1859. As the Gold Rush emerged in California, the need for order in the mining districts became critical. The miners made their own rudimentary mining laws. Their system, based initially on custom, became sanctioned by judicial decisions and eventually was incorporated into state laws. Early federal policy was one of benign neglect. Congress designated mineral lands policy during the 1850's and 1860's. In 1866 and 1870, Congress validated the miners' lode and placer claims, respectively, on public lands. The public domain lands were declared "free and open to exploration...by all citizens of the United States" (Wilkinson and Anderson 1985).

Mineral Production and Use, 1870 to 1920

Mineral use expanded rapidly as agriculture and industrialization continued to grow. The first Bessemer furnace for making steel by blasting air through the metal to remove carbon and other elements began operation in 1865. The open-hearth method which produced higher quality steel was introduced in the late 1860's. Its production surpassed the Bessemer process by 1908. As late as 1886 more than half the U.S. pig iron and steel output was used by the expanding railroad system. Technology to vary steel composition to provide different properties for special uses raised the demand for many mineral commodities which previously were sparsely used, including chromium, nickel, molybdenum, tungsten, fluorspar, and many others (Dorr n.d.).

The opening of the first commercial electric power station in 1880 and rapid electrification by industry and domestic uses after 1900 accelerated the demand for copper. U.S. copper production rose from 30,000 tons in 1880 to 591,000 tons in 1920. The use of lead for storage batteries and cable sheathing accompanied the growth of electricity (Dorr n.d.).

Industrialization, urbanization, and building an infrastructure for the country required enormous amounts of construction materials. Demands for the common nonmetallic minerals rose rapidly—sand, gravel, crushed stone, cutstone, cement, lime, clay, gypsum, and asbestos. Steel and many other metals were also required, especially as steel revolutionized the construction of multistoried buildings and bridge construction (Dorr n.d.).

The production of fossil fuels in terms of physical volume expanded by a factor of 11 between 1870 and 1920. Production in terms of British thermal units (BTU's) went from 1 quadrillion BTU's in 1870 to more than 20 quadrillion in 1920. Coal provided practically all the energy from fossil fuel resources in 1870. Crude oil constituted less than 0.5%. In 1920, coal, mainly bituminous, made up 83% of the fossil fuel energy. Crude oil and natural gas made up only 17%, even though the number of oil and gas wells rose from 15,000 in 1870 to 258,000 in 1920. The use of water power for electricity, which began at the end of the 19th century, added only 3% to the BTU production from fossil fuel resources in 1920 (U.S. Department of Commerce 1975). Fossil fuels not only expanded energy production and use, they also replaced most of the fuelwood use that dominated energy sources in the first half of the 19th Century.

The physical volume of ferrous metal output expanded by a factor of 8 between 1880 and 1920. For all metals the growth factor was 5. Nonmetal minerals output expanded by a factor of 4.5 (U.S. Department of Commerce 1975). Clearly iron and steel and fossil fuels were great technological forces in the industrialization, urbanization, and transportation development in the United States during this period of national growth. Their development added greatly to the wealth of the nation. Their production involved relatively few acres of land. Their contribution to America's productivity in various ways, both direct and indirect, reduced the pressures of a growing population on the land and its renewable resources, especially the timber resource.

Water Resources Planning and Development, 1784–1920

The Period 1784–1870

Early water resources planning focused on inland and coastwise transportation. In 1784, for example, George Washington helped establish the Potowmack Canal

Company to build a canal with several locks so barges could bypass the Great Falls of the Potomac River above Washington. The canal provided a water route from the coast to the farms and settlements in the hinterlands. It was used from 1802 to 1830, when the Chesapeake and Ohio Canal was opened on the Maryland side of the river. Similar canals were planned for the James, Susquehanna, Delaware, Mohawk, and other rivers. Private companies were favored to build them. Private capital, however, was too limited to complete many of the planned facilities and led to efforts to get federal assistance for river improvement works (American Public Works Association 1976, Linsley 1979, Schad 1979, Weber 1979).

The issue of federal funding for canals was debated often in early Congress. Federal funds were approved in 1806 to build a National Pike to link the undeveloped areas of the Northwest Territories beyond the Appalachians with turnpikes being built from Washington to Baltimore. Federal assistance for canals, however, foundered on a continuing constitutional dispute between "national" proponents and strict constructionists. This deadlock was resolved by the Supreme Court in 1824 in the famous Gibbons vs. Ogden case. Chief Justice John Marshall, who decided the case, ruled that Congress's constitutional power to regulate interstate commerce included power over navigation "within the limits of every state in the Union so far as that navigation may be in any manner connected with commerce..." (Linsley 1979, Schad 1979, U.S. Department of Agriculture 1972, Weber 1979).

The dispute about federal funds for waterways improvement did not preclude planning for canals. The Secretary of Treasury, Albert Gallatin, was directed by Congress to prepare a Report on Roads and Canals which was delivered in 1808. It can be viewed as the first comprehensive water resource development plan in the United States. It covered canals to facilitate inland navigation along the Atlantic coast from Massachusetts to North Carolina; canal systems for four rivers draining into the Atlantic, including turnpikes from their headwaters and across the Appalachians to four western rivers; and canals linking the Hudson River to Lake Champlain and Lake Ontario and around the Niagara's falls and rapids to open a water route from the Great Lakes to the Atlantic Seaboard. John C. Calhoun drew up similar plans after the War of 1812. By 1816, however, there were only 100 miles of canals despite their advantages of cheaper and faster transportation (Burges 1979, Linsley 1979, Schad 1979, Weber 1979).

The famous Erie Canal was started in 1817 and completed in 1825. The 363-mile system cost $17 million and earned $500,000 in its first year of operation. Its success accelerated canal building in other states. By 1830, there were 1,300 miles of canals, and by 1840, there were 3,300 miles in use. Few had the economic potential of the Erie Canal. By 1850, most canals that could have been built with private and state funds had been constructed (Burges 1979). Public and private spending for canal construction from 1815 to 1860 totalled almost $200 million; 62% was expended on purely public projects, including major state construction in New York, Ohio, and Pennsylvania; an additional 8% made up the public share of cooperative efforts; and the remaining 30% was privately financed (American Public Works Association 1976).

The passage of the General Survey Act in 1824 (repealed in 1838) marked the beginning of the Army Corps of Engineers' systematic role as the engineering arm of the federal government in water resources planning and development, mainly because it was the only agency in the United States with the required capabilities. The Survey Act authorized the Corps to make survey plans and estimates for roads and canals of national importance. Corps planning and improvement for rivers and harbors was initiated by separate legislation in 1814 for the improvement of the Ohio and Mississippi Rivers, and subsequently extended by periodic omnibus Rivers and Harbors Acts authorizing specific ad hoc improvements and surveys, the first of which was passed in 1826 (U.S. Department of Agriculture 1972).

Flood control remained largely a state and local concern through the first half of the 19th century. National interest emerged as settlement and development grew in the flood-prone lower Mississippi River. In 1849 and 1850, Congress sought to encourage state efforts for flood control through the Swamp Land Acts. The acts granted federal lands subject to flooding in Arkansas, Louisiana, Mississippi, and Missouri to those states with the condition that funds from their sale would be used for flood protection and to reclaim floodlands for cultivation. The acts generally failed in this purpose, but they may have helped establish many of the levee districts and flood control districts which later facilitated joint federal and state/local efforts to control flooding on the Mississippi. In the 1850's and 1860's, the Corps of Engineers surveyed the flood problem of the Mississippi in response to congressional direction. The Corps reported on a need for extensive levees, but their costs exceeded the financial means of the states and local communities. Proposals for federal financing failed in part because of post-Civil War sectionalism (U.S. Department of Agriculture 1972, Weber 1979).

The 1870–1920 Period

The expansion of railroads after 1840 greatly reduced the cost and increased the speed of overland transport for people and goods. Most canals lost their profitability and many were abandoned (Weber 1979).

Congressionally-directed river and harbor improvement projects increased greatly after the Civil War. State and local demands became the source of many of these projects. The authority for deciding whether a project was worth improving was the sole responsibility of Congress, although after 1884, Congress required a Corps district engineer's preliminary assessment, as to whether "said harbor or river is worthy of improvement." In 1902, a national Board of Engineers for Rivers and Harbors was established to review preliminary examinations, surveys, projects or project changes, and evaluate the commercial potential of the proposed improvements

in relation to their cost of construction and maintenance. The Board provided the Corps of Engineers a means for culling infeasible projects and reducing congressional endorsement of unsound proposals (U.S. Department of Agriculture 1972).

Toll charges for watercraft passing through navigational improvement projects were prohibited by federal policy. This policy had its roots in the Northwest Ordinance and the acts admitting new states to the Union. Shippers could not be charged for passage through navigable waters; they were "common highways and forever free" (U.S. Department of Agriculture 1972).

A clear federal role in flood control did not begin to develop until 1874, when Congress, after a disastrous flood, appointed a commission to prepare a permanent plan to reclaim those parts of the Mississippi Valley subject to flooding. The commission's report presented alternative methods of control and a severe critique of the uncoordinated and ineffective local levee systems. In 1879, those findings led a Mississippi River Commission, including three Corps members, three civilians, and a U.S. Geological Survey representative, to survey the river and prepare a plan to improve navigation and prevent floods. Funding, however, remained limited to channel improvement for navigation and prohibited spending for levees. A similar group led by the Corps was set up in 1893 to develop plans to prevent flooding and protect navigability for the Sacremento and San Joaquin Rivers. After major floods in 1915 and 1916, these initiatives were reinforced by the Flood Control Act of 1917 giving the Corps authority for both planning and constructing flood control works on the Mississippi and Sacremento Rivers. The Act also extended the Rivers and Harbors Board review authority over plans and expenditures to flood control works. It also provided that at least one-half of the costs of levee construction be covered by benefitting states and localities (U.S. Department of Agriculture 1972).

States continued to have a primary role in flood control. Their efforts had varied results. The best were exemplified in Ohio by the establishment of the Miami Conservancy District, after catastrophic flooding that took hundreds of lives and caused damage totaling millions of dollars in 1913, to obtain overall flood protection for the entire Miami Valley. The citizens' charge was expressed this way, "The valley has suffered a calamity that must not be allowed to occur again. Find a way out." A comprehensive unprecedented systems approach was taken covering the entire valley basin. The design went beyond the conventional wisdom of the day in which flood control was based on levee construction and channel improvements. It also included dams and retarding basins. The results were exemplary and so effective that flooding never again became a problem after the system was implemented (Burges 1979, U.S. Department of Agriculture 1972).

Federal interest in water power development and irrigation also emerged in the late 19th century. In 1879 and thereafter, Congress passed special laws authorizing either the leasing of water power or "surplus water" to private companies by the Secretary of War, or the construction of private power dams. The Carey Act in 1894 provided for grants to states with public domain lands for reclamation purposes. An appreciation of the role of forest cover for flood prevention and the protection of water supplies and stream flow (watersheds) also emerged toward the end of the 19th century. It was epitomized in the 1891 legislation authorizing the President to establish forest reserves. That legislation was partly motivated by flood control concerns as reflected among its stated objectives "for the protection of water flows." The main objective, however, was timber conservation (U.S. Department of Agriculture 1972).

Multipurpose water resource planning after 1900 became a widely supported new expectation and goal for a sound and rational approach to water resources development. It was an expression and aspiration of the conservation movement of that time. It was also linked to an apparent need for more widespread and successful settlement of the West, the dispersal and growth of the American population, economic development of the western resources, and integration of the regional economics of the Nation (American Public Works Association 1976).

The 1908 report of the Inland Waterway Commission, appointed by President Theodore Roosevelt, defined the multipurpose concept clearly. It recommended that federal rivers and harbors improvement reports reflect all the water uses that could benefit from proposed projects including flood control, water power, irrigation, and even pollution control as it affected navigation. The commission also proposed that both local and national benefits be taken into account "with a view to equitable distribution of costs and benefits." It also called for a National Waterways Commission to coordinate the efforts of the Corps of Engineers, Reclamation Service, U.S. Department of Agriculture, Bureau of Corporations, and other federal agencies making multipurpose plans for waterways, in cooperation with state and local governments. The National Conservation Commission, appointed by President Roosevelt, urged similar multipurpose planning for waterway improvements in 1909, as did the joint Congressional National Waterways Commission Report in 1912.

Legislation for a multipurpose water resource planning agency, a waterways commission, originally proposed in 1907, was passed in 1917. Its members, however, were never appointed, and in 1920, the law providing for the commission was repealed by the Federal Water Power Act (U.S. Department of Agriculture 1972). This act provided for federal power development and authorized the Federal Power Commission to engage in comprehensive broad water resources planning.

THE RISE OF CONSERVATION AND LAND MANAGEMENT BY THE FEDERAL GOVERNMENT

Early Awareness of Resource and Conservation Problems and Needs

Starting in the colonial days, there emerged a recognition and concern that farming often produced conditions that led to soil erosion, loss of productivity, and offsite

damages to streams. Those perceptions and concerns, however, were limited to a relatively few educated farmers and leaders all through colonial times and until after the Civil War. The early leaders—Jared Eliot (1685–1763), Samuel Deane (1733–1814), Solomon Drown (1753–1834), John Taylor (1753–1824), John Lorain (1764–1819), Isaac Hill (1789–1851), Nicholas Sorsby (mid 19th Century), Edmund Ruffin (1794–1865), and others—recognized that soil erosion was a basic problem in farm production; it reduced productivity and led to impoverishment of the soil and the farm family who tried to remain on the same land (McDonald 1941). National leaders such as Thomas Jefferson and George Washington shared the interests and concerns of this group (Rasmussen 1974, 1981).

These leaders appeared in all the original colonies and states. They experimented with soil cultivation and erosion, published their findings and recommendations and shared their views with neighbors and many interested groups. Their efforts to prevent soil depletion were successful on their own farms. They explained erosion and its causes including wind erosion and gullying, the use of drainage and ditches, the effects of plowing, and the advantages of contour plowing. They knew the importance of organic materials, manuring, soil-building crops, and crop rotations in preventing erosion and maintaining fertility. They advocated the liberal use of lime, or marl as it was known then. They understood the agronomic and economic consequences of erosion and its effects on stream sedimentation and flooding (McDonald 1941).

To raise interest in soil erosion and agriculture, many of the leaders advocated and supported the establishment of agricultural societies and organizations and wider distribution of books, pamphlets, and farm journals on agriculture. The scientific societies, such as the American Philosophical Society and the American Academy of Arts and Science, were organized early. The agricultural societies followed. The first, the Philadelphia Society for Promoting Agriculture, was established in 1785. The South Carolina Society for Promoting and Improving Agriculture and Other Rural Concerns came later in the same year. More followed in other states. Their members were professional men who could afford to experiment and to use and adapt innovations from abroad. The agricultural societies focused on the best solutions for problems of broad importance and awarded premiums. Although they were real pioneers in advancing agricultural knowledge, they appear to have had little direct influence on the mass of small farmers (Rasmussen 1974).

Farm journals were developed for regular distribution to practicing farmers. County level organizations sponsored fairs for the mass of farm people. States supported these organizations with grants. The fairs focused on premiums for exhibits of better looking crops and fatter animals, particularly in New England (Rasmussen 1974).

Some progress was made before the Civil War in improving farming methods and erosion control. Ruffin's efforts eventually popularized the use of marl and other improvements. However, the outbreak of the Civil War, westward expansion and the economic pressures of commercial agricultural after the war diverted attention from soil erosion and its control for almost 75 years. The early leaders for improved farm practices were too few, the incentives for the huge mass of farmers too weak, and the alternative opportunities to settle new lands too strong to form any strong consensus for soil conservation in the farming community or the growing urban population. The great pressure after 1860 was to settle the public domain and encourage economic development through agricultural expansion on the western lands (Rasmussen 1981, Roth n.d.).

The federal interest in agriculture beyond the settlement policy was first reflected in the U.S. Census in 1840. It was the first census to collect agricultural information. One year earlier, Congress appropriated $1,000 for the Patent Office to establish a program to collect and distribute seeds and plants. The interest within the States in advancing agriculture appears to have been somewhat stronger. Michigan and Pennsylvania established state agricultural colleges in 1855, Maryland in 1856, and Iowa in 1858. A movement for federal aid to do more had been underway for 20 years (Rasmussen 1974).

Before 1860, the concern for the forest resources was limited to early federal action to reserve live oak trees for naval construction, sporadic efforts at tree planting, and fears of a fuelwood supply crisis, particularly in towns and cities of the Northeast, as firewood became more expensive. Among rural residents and farmers who made up most of the population and usually had woodlots of their own, there appears to have been little concern. For the settlers, the dense forests were an obstacle to farming and a difficult task to clear. Lumber supplies were abundant. The timber resource still seemed virtually endless. The center of the commercial lumber industry remained in the Northeast with New York still the leading producer in the 1850's. Lumber production was largely a local activity dependent upon thousands of small mills with small outputs (Davis 1983).

The grasslands of the West were still unimportant in 1860, except in Texas. Grazing livestock was largely a frontier activity permitted freely on the public domain. Cattle raising interests appeared to focus largely on improving their stock.

Formation of the Department of Agriculture and Land Grant College System

The year 1862 marked the beginning of the U.S. Department of Agriculture and the Land Grant College System. They were to play an increasing role in improving the management and productivity of agriculture and forestry. The Department was established in 1862 with a commissioner responsible to the President. Its objectives were to collect and distribute useful agricultural information; introduce valuable plants and animals; respond to farmers' inquiries; test farm implements; do research on soils, grains, fruits, plants, vegetables, and manure; provide instruction in botany and entomology; and establish a library (Baker et al. 1963). In the same

year, Congress authorized land grants to states and the use of revenues from the sale of grant lands to establish and support a college in each state to teach subjects related to agriculture and the mechanical arts. Although both institutions were criticized in their developmental phases, their capability and services became increasingly recognized.

Some of the early work of the Department improved control methods for animal diseases and led to the establishment of a Bureau of Animal Industry with regulatory powers for animal disease control by 1884. In 1887, Congress passed the Hatch Act which provided grants to the State Land Grant Colleges through the Department to establish agricultural experiment stations. This linked the Department closely with the stations and colleges, expanded the research capability, and brought system and direction to the colleges for their future development (Baker et al. 1963). The experiment stations earned the support of farmers because their research provided useful, practicable results that added to productivity and farm earnings. That included soils analysis, fertilizer recommendations, ways to control plant and animal diseases, and marketing aids. In 1889, after a long period of debate, Congress elevated the Department to Cabinet status.

Both the Department and Land Grant Colleges sought ways to accelerate the transfer and adoption of their research results. The college faculties and researchers emphasized farmer institutes, lecture tours, short courses, instruction at fairs, and publications. The Department emphasized ways to reach the farmers by working more directly through their local organizations and offering on-farm demonstrations. Both were concerned that the results of research were not reaching all farmers and making their maximum contribution to productivity. Not all results were always practicable. But many were successful and contributed to the control of animal pests such as the cattle ticks, reduction of boll weevil damages, some new crops, improved seeds, and better soil cultivation practices. Overall increases in crop and livestock yields, however, remained relatively small (Jenkins 1980).

Concern for more effective transfer of research findings and a more productive agriculture led to the passage of the Smith-Lever Act in 1914 for the organization of the Cooperative Federal-State Extension System at each of the Land Grant Colleges. This linked agricultural research with education of the local farmers in each county. The system was supported by federal matching grant funds to the states. Although the colleges thought differently at first, they agreed to design the system based on the Department's local project and local resident agent approach to the transfer of research findings and technology to local farmers.

The period of 1914 to 1920 was one of organizational development of the Extension System at the county and state level throughout the rural United States. It was also a period of growth in public awareness and acceptance of the system and its structure. Because of the timing, a large part of the early extension effort was devoted to the narrow aim of drastically increasing food and fiber production to meet the demands of the war. Agents also found time to teach vaccination of hogs against cholera and to find ways to offset labor shortages, preserve foods, cull livestock, and locate good quality horses and mules. They also assisted liberty loan programs, draft boards, and Red Cross drives. By the end of 1920, the Cooperative Extension Service had a visible national organization. U.S. agriculture had a highly coordinated research, education, and extension system to develop new technology to raise output per farmer and per acre and a way to transfer it quickly and effectively to local farmers in all parts of the nation (Jenkins 1980).

Forestry also was getting a start in the Department of Agriculture. In 1876, the American Association for the Advancement of Science and the American Forestry Association proposed, and Congress authorized, the position of federal forest agent within the Department. Franklin Hough, who, as superintendent of the 1870 Census, had developed a growing concern for timber supplies, became the first appointee. His assignment was to study timber needs and supplies, ways to preserve and renew forests, and their influence on climate. His work led to the formation of a Division of Forestry in 1886 and then a Bureau in 1887. Bernard Fernow, a well-trained German forester, succeeded Nathaniel Eggleston who held the position briefly after Hough. Fernow lectured and published a wealth of material about the problems, needs, and objectives of professional forestry as well as appropriate procedures for harvesting timber. He also encouraged constructive management of the forest reserves established in 1891. His efforts, and those of a few other trained foresters, helped to expand appreciation for European approaches to forest management among the late 19th century conservation movement leaders, who were focussing attention on the public forest lands (Davis 1983, Gates 1968).

Gifford Pinchot, who was to become the renowned leader of the conservation movement, succeeded Fernow as Chief of the Bureau of Forestry in 1898. A skilled administrator, well-trained in forestry, he expanded the forestry staff severalfold and developed cooperative forest management and reforestation programs with many timber companies. He also extended the research program from timber physics to the study of the forest itself. At the same time, he campaigned strongly for the conservation movement and encouraged the transfer of the forest reserves to the Department of Agriculture. That transfer came in 1905, and the Bureau, in the same year, became the Forest Service, emphasizing a service commitment to the public. In 1907, the forest reserves were renamed national forests to signal that their resources were to be managed for the use of all the American people (Davis 1983).

The Emergence of Forestry at the State Level

The first efforts for professional forestry education began with forestry lectures in the 1870's at Cornell University, the University of Michigan, and other colleges, usually in departments of botany or horticulture.

The courses emphasized tree planting and the agricultural aspects of forestry. The first 4-year curriculum in forestry was established by the State of New York, in 1898, at Cornell University. Yale University founded a professional forestry curriculum in 1900, the same year that the Society of American Foresters was formed. Other schools soon followed (Davis 1983).

The first efforts to apply forestry on a large property, as practiced in Europe, began in 1892, when George Vanderbilt hired Gifford Pinchot to manage the extensive forests on his 100,000-acre Biltmore Estate in the mountains of North Carolina. Although this effort to apply silviculture proved unprofitable, it marked the beginning of professional forestry practice in the United States. Now a part of the national forests in North Carolina, the Biltmore forests are commemorated as "The Cradle of American Forestry" (Davis 1983).

In 1885, California and New York were among the first four states to establish state forestry programs. They responded to farmer concerns about water supply, lumbermen concerns about losses of valuable timber from fire, politicians wanting to safeguard their states' economic base, and private citizens concerns for conserving forest resources. Ohio and Colorado also formed forestry agencies in 1885. These and other early state forestry agencies remained small. Only New York, among the first four, had uninterrupted development. The young state forestry agencies received a welcome boost from the Weeks Act of 1911, which provided federal grants up to $10,000 for qualified state forest protection programs (Davis 1983).

The Conservation Movement

The conservation movement of the late 19th and early 20th centuries emerged from growing national concerns about the condition and trend of natural resources and particularly, the disposition of the remaining public lands. The resources and interests included the forests, their waters and watersheds, wildlife and fisheries, aesthetic values, recreation opportunities, the rangelands, and soil. Each of these interests had their own supporters and often the support of the users—irrigators, graziers, lumbermen, and sportsmen. These groups frequently found mutual or complementary objectives and often combined their support for selected public initiatives at both federal and state levels. Their goals ranged from resource preservation to wise use over time and the maintenance of economic opportunity. Although the wise use theme came to dominate the movement, it did not suppress the interests in preservation or economic opportunity.

The efforts of the various interests in the conservation movement were epitomized in the reservation of public lands, legislation and programs for resource protection and management, regulation of hunting, and preservation of parklands, natural monuments, and historic sites. These actions slowed the conversion and utilization of resources of public domain lands and helped to reverse downward trends in resource conditions and productivity. The results came slowly, but perceptively, even though they did not bring ideal use and management to all resources on all lands.

Establishment of Federal Reserves

The movement to reserve public lands from private development and retain them under federal ownership and management emerged from first sporadic, then converging and sometimes conflicting interests in aesthetic preservation and conservation of resources in the utilitarian sense of wise use. Congress had been reserving areas of the public domain since the Ordinance of 1785. However, there was no general policy objective for reserves. Thus, the origin of federal reserves did not have a sharp resource-oriented policy beginning or path (Clawson 1964).

National Parks

Reserves for park purposes were among the notable early actions. Congressional interests in lands of extraordinary beauty and uniqueness led to setting aside four sections of the Hot Springs of Arkansas in 1832 which later became the Hot Springs National Park. In 1864, Congress granted the State of California lands that eventually became the Yosemite National Park for "public use, resort and recreation." Then, in 1872, the Yellowstone Park Reserve of 2.2 million acres was established "as a park or pleasuring ground for the benefit and enjoyment of the people." The act creating the park also gave the Secretary of the Interior the authority to manage the park reserves. This was long before those lands could be accessed and widely used by the American people. Three more parks were established by 1900, bringing park area to more than 4 million acres. In 1916, the National Park Service was established and the concept of a system of national parks defined. That system included the national monuments, which were authorized in 1906 to preserve prehistoric and historic sites and relics, geologic spectacles, botanical reserves, and wild animal reservations. By 1920, the parks and monuments with bird and game reserves totalled almost 9 million acres (Davis 1983, Gates 1968, Hibbard 1924).

State Parks

The concept of state parks did not emerge formally until the end of the 19th century. States had reserved forests and other areas for various purposes; but, the best claim to the first full-fledged state park is attributed to the Niagara State Reservation at the falls of the Niagara River established in 1885. In that same year, New York State also established the Adirondack and Catskill State Parks encompassing 2.25 million acres of state and private lands. The state lands were declared a wilderness preserve to remain "forever wild." Congress had authorized and California had accepted the grant of Yosemite Valley and the nearby Mariposa Grove of giant sequoias in 1866 as a state park; but, those lands were

receded to the federal government in 1906 and became the Yosemite National Park.

About 1900, more states began to set aside historic, scenic, and recreational areas for park purposes. Mount Greylock was established in Massachusetts in 1898. Minnesota acquired two parks in 1893, Birch Coulee, a Sioux battleground, and Itasca at the headwaters of the Mississippi. The Palisades Interstate Park was established along the lower Hudson River in 1895. California initiated Big Basin Redwoods State Park in 1900.

Such initiatives, the formation of the National Park System and activities of nature advocates and outdoor interests, gave momentum to efforts on behalf of state and local parks. A nationwide campaign slowly emerged under the general leadership of Stephen T. Mather, the first director of the National Park Service. With the support of the Secretary of the Interior and the Governor of Iowa, he was able to convene a National Conference on State Parks in Des Moines in 1921. Two hundred representatives—mostly private citizens—participated from 25 states. The success of the Conference established it as a permanent organization. The area of state parks at that time was just a few million acres in a few states with the bulk of the acreage concentrated in New York State.

Water Power and Reservoir Sites

Authority was provided as early as 1879 to reserve land for access to potential water power. However, there were relatively few reservations, most of which were being developed by private companies. In 1910, because of complications with reservoir sites, new legislation was passed that accelerated the rate of federal reservation of both power and reservoir sites. By 1920, about 5 million acres had been reserved. They retained a vast capacity for power and water storage in the hands of the federal government. However, no comprehensive plans had been made for development of these sites (Hibbard 1924).

Reclamation Reserves

By 1900, the slow progress in irrigation and desert land reclamation made it clear that private initiatives and land grants to states for reclamation through large impoundments and water diversion projects were not working well. Basically, the costs were too great for homesteaders to repay fully. Irrigation interests had opposed creation of federal reserves for reclaimable lands. In 1902, however, they supported the Newlands Act, which authorized the Secretary of the Interior to locate, construct, operate, and maintain projects to store, divert, and develop water for reclamation. The Department of the Interior established the Reclamation Service for these purposes. It was a new departure in public land policy. The act authorized the federal government to make land useable where and when it was not profitable for the private sector to do so. In the next 20 years, 26 projects were undertaken at a cost of $135 million. Only about 1 million acres were irrigated and patented for crop production by 1920. Much speculation was involved in the lands to be irrigated. Settlers who homesteaded lands to be reclaimed found irrigation came more slowly than expected; they suffered from droughts and were largely unable to pay for the lands on the anticipated short schedule. Reclamation was a new and expensive experience for the federal government. Progress was slow, troubled, and difficult. There were 16 million acres in reclamation reserves but the reclamation program in 1920 fell far short of its hope and promise for both government and the settlers (Gates 1968, Hibbard 1924).

Forest Reserves

The forest reserves were first proclaimed in 1891 and expanded very rapidly, reaching 161 million acres by 1920. They were the single largest segment of the public lands withdrawn for federal ownership and management, making up almost 60% of all federal reserves in 1920. They were the outcome of a campaign to assure long-term timber supplies from public lands (Hibbard 1924).

Concern for timber supplies was being expressed publicly as early as 1849 when the Commissioner of Patents addressed "the waste of valuable timber in the United States" in his 1849 annual report. Similar views and articles followed in the 1850's and 1860's (Davis 1983). There were efforts to encourage tree planting such as Arbor Day, first observed in Nebraska in 1872. In 1873, the Timber Culture Act offered 160 acres to homesteaders who would plant 40 acres of trees. The act failed in its purpose and was repealed in 1891. In the 1870's there was a growing fear that the depletion of white pine in the Northeast and Lake States would lead to use of inferior southern or West Coast species. This was evidenced by rising prices and the expectation of even higher prices because of costs of shipment from other regions. The American Forestry Association was organized in 1875 and sponsored national forestry conferences. Some state forestry societies, commissions, and boards of forestry were organized, and many accounts were written of wasteful and destructive timber harvesting on public lands (Gates 1968).

Before 1878, there were no specific authorities for private acquisition of public domain timber. Nevertheless, much timberland was moving into private hands through the Preemption Act of 1841, the Homestead Act, Presidential proclamations offering timberland for sale to the highest bidder, and some theft. In the 1870's and 1880's, the Department of the Interior sought legislation to manage public timberlands. But, in 1878, Congress in several ways actually liberalized private access and timber cutting on public domain lands not suitable for homesteading in the far western states (Gates 1968, Hibbard 1924).

The Report of the Forests of North America, a part of the Census of 1880, advised that the remaining white pine in the Lakes States would be exhausted in 11 to 12 years at the existing rates of harvest. Although discredited by trade journals, the report influenced prices and helped amplify the growing concern about timber supplies (Gates 1968).

As a result of the growing concern about timber supplies and the initiative of a few leaders concerned about the use of public forests, Congress, in a late-night conference, inserted an amendment to an 1891 land bill authorizing the President to reserve forest lands, but did not include any provisions for their management. Although this authorization had not been previously discussed, Congress passed the land bill the next and last day before adjournment based only on a reading of that amendment. President Harrison soon reserved 11 million acres, and in 1897 President Cleveland, at the end of his term, set aside additional lands which more than doubled the forest reserve area.

There was a strong outcry, particularly from western interests and western Congressmen. Mining, grazing, and other uses were not permitted on the reserves. This prohibition was reversed when a new Congress, responding to this western issue, passed the 1897 Organic Act providing for the use and management of the reserves. The act removed the prohibition and permitted grazing, mining, and other uses. It also granted miners free access to the timber and stone needed for their operations.

In 1905, when the administration of the reserves was transferred from the Department of the Interior to the Department of Agriculture under the Forest Service, Congress provided that minerals management remain with Interior. The Forest Service, however, instituted regulations to restrict the use and occupancy of remaining claims to those activities necessary for working the claim. These regulations responded to widespread abuses of the mining laws for nonmining purposes. It did not try to regulate valid prospecting or mining activity (Wilkinson and Anderson 1985).

Support for expanding the forest reserves remained tenuous. Congress, concerned about further additions, passed a law in 1907 requiring Congressional review and approval of reserve proclamations. However, President Theodore Roosevelt, a strong supporter of the conservation movement, who shared the interests of Gifford Pinchot and other leaders of the movement, reserved even more areas before signing this bill into law in that year.

President Roosevelt issued 17 proclamations at that time, affecting national forests in Arizona, California, New Mexico, Nevada, and Utah. The papers and maps describing the affected areas, as well as draft proclamations, had been developed by the Forest Service earlier in the year. To obtain the Chief Forester's approval and acceptance for the proposed proclamations before he left for an extended absence, the Forest Service Chief of Boundaries, Arthur C. Ringland, travelled to Lansing, Michigan at the end of May 1897 to meet with Gifford Pinchot. Pinchot was there to receive an honorary degree from Michigan State College. Ringland recalls this dramatic meeting with Pinchot in this way:

> ...I carried these papers, maps and descriptions in a golf bag that I kept with me even in my pullman berth during the trip. Upon arrival at the Hotel Downey, Mr. Pinchot's sitting room was cleared of furniture and the maps spread on the floor. We took off our shoes, rolled up our trousers, and in stocking feet crawled all over the maps with Mr. Pinchot carrying a heavy blue pencil in his hand. With this pencil, he indicated the areas to be included in the proclamation.
>
> When Mr. Pinchot had made his final determinations, I immediately carried the papers back to Washington where the Boundaries staff prepared them for signature and proclamation by President Roosevelt.[6]

In 1911, Congress expanded the authority to add to the reserves, or national forests as they were renamed in 1907. The Weeks Act of 1911 authorized the Forest Service to acquire and manage forests on the head waters of navigable streams. The same act gave consent to states to form interstate compacts to conserve forests and water supplies and authorized annual incentive grants to states with qualifying programs to protect forested watersheds from wildfires. The act was addressed essentially to the eastern states, where forestlands were almost entirely in private ownership. It responded to a growing concern in the East about the influence of deforested lands on periodic flooding of cities and towns, the loss of scenic areas to the recreation industry, and the general reduction of the original forest inventory. By 1923, 1.6 million acres had been purchased in three or four eastern states. Many more million acres were being identified and studied for acquisition in other states (Davis 1983, Gates 1968, Hibbard 1924).

Mineral Reserves

Efforts were made during the 1800's to control the development of mineral resources on public lands, but little progress occurred before 1905. Most of the earlier focus was on coal lands. They were not subject to the General Mineral Law of 1872, and demand for coal was rising rapidly in the latter part of the 19th and early 20th Centuries. Congress first provided for disposal of coal lands in 1864 by authorizing a minimum sale price of $25 per acre. In 1873, the price was reduced to $10 per acre for coal lands farther than 15 miles from a railroad, and to $15 an acre for those that were closer. A total of 603,006 acres were sold between 1873 and 1923 at a total price of $11.9 million (Hibbard 1924).

In the latter part of the 19th Century, recognition of the importance and value of coal lands increased. Issues arose about withdrawing them from entry and excluding them from agricultural entry. When the Geological Survey, established in 1879, found after 1900 that large areas of valuable coal lands in the West had been acquired through agricultural entries, the President undertook decisive action. He directed the Secretary of Interior to withdraw all such valuable coal lands from entry for proper examination and classification. In 1906 and 1907, 66 million acres which were presumed to hold coal deposits were withdrawn by proclamation. Millions

[6] *Interview of Arthur C. Ringland conducted by Amelia Fry, University of California Oral History Office on November 25, 1953. In: National Forest Additions by Presidential Proclamation. Berkeley, CA: Harris Collingwood Library of Congress. Appendix.*

of these acres, however, were soon determined to have no coal and were returned for agricultural entry. Others were appraised for their coal deposits and some were sold for $75 to $100 an acre between 1906 and 1909 without any change in the existing law. It was interpreted that the legislated "not less than" price did not define a ceiling price. But the issue remained as to what to do with the surface rights of the retained coal land withdrawals which were also valuable for farming.

Congress resolved this issue in 1910 with legislation permitting entry of coal lands for farming while reserving the government right to dispose of the coal separately. Settlers holding surface rights were protected against losses from the discovery and removal of coal by reimbursement for their loss. They were also permitted to dig coal for their own use.

The Withdrawal Act of 1910 provided for the withdrawal of other minerals, such as oil, gas, nitrate, phosphate, potash, and asphaltic minerals, as well as coal (many acres of which had previously been withdrawn from entry by proclamation). At the end of the Taft Administration in 1913, most of the mineral resources on the public domain were completely locked up. Leasing of mineral withdrawals was first authorized for the development of coal lands in Alaska in 1914 and for potassium deposits in 1917. Federal leasing became the general policy for fuel and fertilizer minerals on withdrawn public lands under the Minerals Leasing Act of 1920. Awards for mineral leases were based on competitive bidding or as the Secretary of Interior directed. The Secretary of the Interior also was authorized to attach conditions to the leases to protect public resources and the public interest. This provision essentially restricted the miners' previously unqualified access to fuel and fertilizer minerals on the federal lands.

Between 1920 and 1923, 26,036 lease applications were filed in 22 states under the Mining Leasing Act. At that time, there were almost 2.5 million acres of phosphate land and 6.4 million acres of oil land withdrawals in addition to the 34 million acres of coal land withdrawals (Hibbard 1924, Robbins 1956, Wilkinson and Anderson 1985).

Wildlife Management Development in the Late 19th and Early 20th Centuries

Before the Civil War, efforts of organized sportsmen from larger towns and cities, a few scientists, and fewer nature enthusiasts produced laws in most states for closed seasons for various game species. They were generally ineffective. Rural counties and towns where the game was found exempted themselves from the state laws. Effective local or state enforcement was lacking.

The concept for central authority for management of fish and wildlife only emerged after the Civil War when Congress, in 1871, set up the U.S. Fisheries Commission and charged it with rehabilitating depleted fisheries. By 1880, almost all states had followed suit and in 1910, nearly every state had some type of agency responsible for protecting its wildlife and replenishing fisheries. Most were poorly funded and their performance varied widely. Nevertheless, raising game fish in hatcheries and stocking ponds, lakes, and streams was widely successful even though it was limited. That success encouraged experimentation in stocking game birds. The greatest early success was with the Chinese ringnecked pheasant, first introduced in Oregon in 1881. By 1900, that success was repeated throughout the Northern United States from coast to coast (Trefethen 1975).

In the late 1800's and early 1900's, state wildlife agencies focused management efforts on small game birds and mammals. There was little big game to manage, except mule deer in the Rockies. Only the bison, protected on national parks and federal refuges, appeared to have an assured survival with the help of an intensive federal management program. The appearance of a sudden and large improvement in the white-tailed deer population in the Northeast provided much hope for wildlife managers. The return of the deer was associated with the net abandonment of pastures and croplands in the 1880's and their reversion to young forest cover. Wildlife managers took advantage of the returning habitat to restore deer throughout the Northeast (Trefethen 1975).

In 1896, Congress created the Division of Biological Survey in the Department of Agriculture by reorganizing and expanding the Division of Economic Ornithology and Mammalogy. Its work included the study of bird distribution and food habitats as they related to agriculture and biological surveys of mammals. The Division gained Bureau status in 1905 and remained with Agriculture until it was transferred to the Department of Interior in 1939 (Davis 1983, Trefethen 1975).

The control of hunting, licensing of hunters, and laws relating to wildlife conservation began to improve notably after 1900. Congress brought the federal government into the wildlife conservation picture with the passage of the Lacey Game and Wild Birds Preservation and Disposition Act in 1900. It made interstate shipment of wild birds and animals and their products taken in violation of state laws a federal offense. In 1913, the passage of the Migratory Bird Act and legislation authorizing the President to enter into international agreements to protect migratory birds brought federal protection and management to migratory fowl. It authorized the Secretary of Agriculture to fix closed seasons when it would be illegal to kill or capture migratory birds. The Treaty between the United States and Great Britain for the Protection of Migratory Birds in the United States and Canada was signed in 1916 (Trefethen 1975).

In these ways the impacts of market hunting and unregulated hunting for food and wildlife products were reduced. It was the result of the wildlife conservation efforts that paralleled the conservation movement which had centered largely on the forests. The influence of a number of early leaders including George Perkins Marsh, an early leader and writer on scientific principles for wildlife resource use and management; George Bird Grinnell, longtime editor of Forest and Stream magazine; Theodore Roosevelt as conservationist, Governor, and

President; and Senator John F. Lacey successfully brought protection to many wildlife species and populations. State efforts to enforce game laws also became more effective.

THE TRANSFORMED HERITAGE AND NEW DIRECTIONS IN 1920

In 1920, more than a billion acres of the public domain, over half the area of the contiguous 48 states, had been transferred to largely private ownership, development, and management. Much acreage east of the prairies had been harvested and cleared of its virgin timber to provide for cropland and pasture, lumber for homes and other purposes, and fuelwood for cooking, heating, and energy. The old growth timber lands of the West were largely unaccessed although some timbering had begun. Over 400 million acres were being plowed for cropland, 750 million were being used for pasture and range, and 567 million remained in forests (table 1). Another 185 million acres had been devoted to other uses including cities and communities, transportation systems, defense and industrial uses, parks, some wildlife areas, and residual unused swamp, desert, and barren rock areas. The settlement of the nation from coast to coast and north to south was largely completed and linked with rail transportation. Minerals development and technology were also making important contributions to national industrialization, urbanization, employment, and wealth.

Much of the original fertility of the soils, timber of the forests, and forage of the prairies and plains had been consumed. Although the process of the transformation has been repeatedly described as wasteful, exploitive, depletive, and fraudulent, much of the wealth of resources was largely transformed to viable homesteads and farm enterprises. Some of the virgin wealth was used to establish and support public schools, colleges, and universities. Some of the private savings from that wealth educated new generations of scientists, professionals, farmers, and business people, and expanded the intellectual resource of the nation. In these ways, much of the regional wealth of a new land became converted to working capital that helped build a new nation, raise the welfare of its people, expand its population, and provide for its defense. At the same time, the process sustained the basic traditions of freedom and democracy in both the political and market arenas.

Settlers and graziers had experienced frequent years of drought and some extended periods of depressed prices and markets. But 1900 to 1920 was a period of record prosperity for farmers and graziers alike. It was also a boom time for the lumber industry in meeting the very strong demands of a growing population for building materials. Economic incentives and professional knowledge and capability for forestry were lacking during most of the 19th and early 20th Centuries. Thus, abundant timber remained the least cost source for basic building materials. Its lumber has provided decades of service, and still does in most of the homes of America to this day.

There were reasons and evidence for concern, however. Would the resilience of the soils, the grasslands, and the forests be sufficient to meet the needs of future generations? Many citizens were unhappy with some of the existing resource conditions. The dimensions of emerging resource problems were difficult to assess. Consensus for change and improvement came very slowly and unevenly. The pressures for public land settlement and economic development through resource use remained strong, both in the private and public sectors. Even the movement for conservation became dominated by the utilitarian concept of wise use.

Soil erosion, which had received the early attention of many agricultural and conservation leaders, became more prevalent. But, awareness of the problem seemed to fade. One of the first farmers' bulletins published by the Department of Agriculture in 1894, "Washed Soils: How to Prevent and Reclaim Them," reported that thousands of acres of fine cropland were eroding and being abandoned annually. It urged farmers to reclaim and use those lands again. Congress approved the first annual appropriation for soil survey work in the same year, \$3,000 to investigate different typical soils and determine their chemical character, physical properties, and the nature of the nitrifying organizisms they contained. Soil surveys usually follow county boundaries. They delineate the areal extent of specific soil types, define their chemical and physical characteristics, and provide interpretive information on feasible uses and management requirements for sustained use. The first soil survey was printed in 1899. Five years later, Congress, recognizing the value of soil survey information to the pubic, passed a resolution for the regular publication of completed surveys (Miller et al. 1985).

In 1910, the Department published additional bulletins on soil conservation and corn cultivation advising farmers that erosion had to be stopped to maintain production and productivity. The response was apparently minimal.

Soil erosion was not forgotten during the conservation movement of 1890–1920. Gifford Pinchot, a chief leader of the movement, was aware of it. But the focus of the movement on timber supplies, public forests, forest management, and generally the resource problems of the arid West appeared to eclipse attention for the soil erosion problem in that period (Miller et al. 1985).

Gifford Pinchot, the leading reformer for conservation, had attempted to coalesce the separate elements of the movement into a unified association and effort. The separate elements often shared common interests and worked together. However, they never actually fused into a single unified organization and movement with common goals and priorities. Forestry, reclamation, water power, flood control, waterway improvement, and mineral leasing interests were making progress in their own way. The advocates of these separate interests were wary that a managerial approach would dilute their specific objectives. Other groups not a part of the Pinchot program, such as wildlife and natural beauty, were similarly advancing their own interests. Each had its own but overlapping followers (Davis 1983).

The nation entered the 1920's and 1930's with 272 million acres of public land reserves, a federal commitment for their productive management, and 200 million acres of unoccupied public lands with open range grazing. The Department of Agriculture and the Land Grant Colleges had a strong commitment and system to reach local farmers more effectively with improved farming methods, materials, and technology through a cooperative extension education program. State efforts for protecting the nation's private forest resources were gaining momentum as the Forest Service was improving the protection of national forests.

A PERIOD OF INSTABILITY AND TRANSITION, 1920–1945

The end of World War I and the rehabilitation of European agriculture brought a collapse in foreign demand for farm production and commodity prices plummeted in 1920 and 1921. A prolonged period of agrarian distress began, from which agriculture did not fully recover until World War II sharply revived farm export demands after 1940.

The collapse of commodity prices and a rigidity in nonagricultural prices and wages, and therefore farm costs, squeezed farm incomes. Average income per capita for the farm population in the 1920's was less than half that of nonfarmers. Farmers were not sharing in the general prosperity of the rest of the nation. When the Great Depression affected the rest of the economy in the 1930's, general farm welfare fell to new lows as both domestic and foreign demands and commodity prices fell (Breimeyer 1983, Paarlberg 1964, Rasmussen 1974).

EXPANSION OF THE FEDERAL ROLE IN LAND USE AND RESOURCE MANAGEMENT

Farm Production Adjustment and Supply Management

During the 1920's, farm groups sought direct federal assistance that would raise commodity prices through export subsidies. These efforts failed (Halcrow 1984). Authority granted to farmers in 1922 to set up cooperatives to market large volumes of commodities, and thus increase their market influence, proved ineffective (Rasmussen 1974).

There were different diagnoses of the problem of farm prices and incomes. One saw agricultural distress as part of a more general problem associated with the collapse of money and credit supply. A changed monetary policy was seen as the remedy. Another viewpoint attributed the agricultural problem to excess production. The remedy in this case was production control. The latter viewpoint prevailed. The nation turned toward federal farm production control that would raise United States commodity prices above the world price structure.

The concept became national policy through the Agricultural Adjustment Act of 1933 (Paarlberg 1983). This act was declared unconstitutional in 1936, but subsequent legislation in 1936 and 1938 retained the federal role in production management. The law was administered by the Department of Agriculture as the federal government became a partner with the farmer in adjusting production and managing supply—a role that has continued to the present. Implementation of the policy reduced crop acreages, provided payments to farmers for participation, and helped support farm commodity prices. It brought financial relief to the farm sector. Full recovery, however, came with the expansion of European demands for farm commodities during World War II (Paarlberg 1964).

During this period, agriculture emerged as a separate economic sector subject to annual national planning as epitomized in production adjustment, supply management, and price support policies. Thus, national agricultural planning was added to the traditional Department of Agriculture roles of research, education, and regulation. Policy objectives now explicitly included maintenance of farm income and welfare, and improving production efficiency (Breimeyer 1983, Paarlberg 1983, Rasmussen 1983).

Other federal programs designed to contribute to the farm income stability and welfare objectives included federal crop insurance, disaster relief payments, resettling farmers from poor land, aiding tenants to purchase their own farms, soil conservation, rural electrification, farm credit, and distribution of surplus commodities to the needy. These programs were all a part of the New Deal of the Roosevelt Administration and constituted what historians have labelled as agricultural reform. In this way, agrarian distress found both relief and reform. And with the help of World War II demands, it also found economic recovery.

Land Use Adjustment and Public Acquisition

During the 1930's, when the Depression intensified the economic distress of farmers, it became evident that many farmers were cultivating lands that were poorly suited for farm crops, low in productivity, and earning below the margin for profitable farming. These lands were labeled submarginal areas. In those areas, farm foreclosures were multiplying, tax delinquency increasing, and farm income dwindling. Frequently, these lands were abandoned after their saleable resources had been liquidated. The land resources often were damaged by drought, floods, erosion, poor farming practices, and neglect.

The New Deal response to these seriously distressed areas was to provide funds to buy the land, retire it from crop use, and redevelop it for pasture, forest, range, park, recreation, wildlife refuge, and other uses. A study and evaluation by the National Resources Board in 1934 recommended that the Government buy and develop 75 million acres of this submarginal farmland in various regions to relieve the distress of its farmers (Ubelaker and Jantz 1986). The Copeland Report on American Forestry, prepared by the Forest Service for the U.S. Senate in 1933 found that "more than 50 million acres

of agricultural land, originally timbered, have been abandoned because they were never suited for agriculture or because they have reached the submarginal class from erosion or other causes. The land is now idle and available for forestry. The area may become still larger in the future" (U.S. Department of Agriculture 1933).

Under Executive Order, some 250 land utilization projects, totalling 11.3 million acres in 45 states were acquired between 1933 and 1946. About 25,000 farm families sold their lands under this program. Over 8,000 received federal help to relocate. More than 9.5 million acres of this area were eventually redeveloped for range, forest, and related multiple uses such as wildlife protection, watersheds, and recreation. Another 1.8 million acres were transformed into wildlife refuges and parks (Wooten 1965).

The bulk of the acquired lands were managed by the Soil Conservation Service of the Department of Agriculture. Ultimately, 5.4 million acres were transferred to the Forest Service; 3.8 million were used to form the national grasslands and the balance were assigned to forest use. Another 5.8 million acres were transferred to other federal agencies, granted or sold to states and local governments, and, in a few cases, sold to private parties. The program did adjust ownership and use to the capabilities of the land. It fell far short, however, of the 75 million acre target proposed by the National Resources Board (Wooten 1965).

Multipurpose Water Basin Planning and Development Expands Rapidly

The western pressure for multipurpose river basin planning and development with federal leadership, financing, and assistance continued to build in the 1920's. Industrial opposition to federal power development delayed its strong emergence until the 1930's. At that time, it virtually exploded with the reinforcement of New Deal programs for public planning, financing, and construction of public works to create jobs and employment during the Depression. Federally-installed hydropower generating capacity in 1920 was no more than 10 thousand kilowatts while privately-owned generating capacity was almost 13 million kilowatts and municipal capacity only some 500,000. By 1945, federal capacity for hydropower generation exceeded 5 million kilowatts, about 10% of the total hydropower supply at that time (U.S. Department of Commerce 1975).

The Federal Power Commission authority for comprehensive water resource development planning provided by the Federal Water Power Act of 1920 was not funded. The Commission devoted its efforts in the 1920's mainly to licensing nonfederal power projects. Licensees, however, were required to show that their plans were adapted to comprehensive development. In the meantime, the Bureau of Reclamation, under the aegis of the Kincaid Act of 1920, investigated the potential for irrigating the Imperial Valley of California by diversion of the lower Colorado River waters. In 1922, the Bureau recommended building a diversion canal and a huge storage reservoir for multipurposes on the Colorado River. It also proposed that all future developments on the Colorado be undertaken by the federal government, reflecting the potential for further multipurpose projects in six other Colorado River Basin states.

The Bureau recommendation was implemented by the Boulder Canyon Project Act of 1928. Its purposes included flood control, navigation, water storage for irrigation, the generation of power as a way to make the project financially self-supporting, and other beneficial uses, particularly municipal water supplies for several cities in southern California. The main structure, the Hoover Dam, was completed in 1935. The first power flowed in 1936. The first irrigation water was delivered in 1940 and eventually served 600,000 acres.

The Hoover Dam became a precedent and symbol for American public works water resource projects in the early 20th century (U.S. Department of Agriculture 1972). It transformed the economy of the Southwest by increasing the supply of both power and water and contributed particularly to rapid economic growth in southern California. It set the stage for similar power and reclamation projects such as the Grand Coulee and Bonneville Dams on the Columbia River, Fort Peck on the Missouri River and Shasta in California (American Public Works Association 1976, Rasmussen 1974).

In 1925, Congress set the path for river basin development projects for the rest of the United States. In that year, it directed the Corps and the Federal Power Commission jointly to prepare a list of the nation's navigable streams and their tributaries (excluding the Colorado River) having power development potentials. Cost estimates were to be made for making stream examinations and surveys with a view to the improvement of such streams for navigation and development for power, flood control, and irrigation. That list was printed in 1927 in House Document 308. Thereafter, Congress authorized the Corps alone to conduct the surveys which became known as the "308 reports." These 308 reports took the Corps over 20 years to complete and provided much of the basis for water resources development during the New Deal and post-World War II periods, including the Tennessee Valley Authority and the Columbia River power system development, both of which were authorized in 1933. The Bureau of Reclamation retained its multipurpose project authority for the Colorado River Basin and continued its investigating role for irrigation improvements in the 17 Western States (U.S. Department of Agriculture 1972).

The emergency programs of the New Deal period provided enormous sums of funding for public works projects and federal work relief efforts which supported many federal water resource development projects as well as state and local government efforts at improvement of water resources. The Public Works Administration provided loans and grants to states and local governments for municipal waterworks, sewage disposal plants, irrigation, flood control, and water power projects. Federal agencies also received grants for irrigation, navigation, power, and flood control projects. The Works Progress Administration similarly financed staffing,

planning assistance, and construction of smaller water resource projects sponsored by state and local governments. Federal financial aid in this period made important contributions to water pollution control and many other water resource improvement projects. During the 1932–1937 period, for example, the total population served by sewage treatment works increased 73% and the number of treatment plants increased by one-third (U.S. Department of Agriculture 1972).

Levees and other water control works were built in the 1920's and into the 1930's by several federal agencies for specific areas under individual project authorities as well as by states, levee boards, cities, counties, districts, and railroads. A consistent public policy and coordination for flood control were a continuing challenge. There were proponents for a national flood control approach. The constitutional issue over the federal role had been settled. It was increasingly accepted that the broad benefits of flood control extended to the entire population. Specific beneficiaries as in the case of power or irrigation were difficult to segregate. Thus, the Flood Control Act of 1936 emerged as a new area of general national planning in the middle of the New Deal era.

The 1936 Act inaugurated a national flood control program. The Corps was given jurisdiction over flood control studies and improvements on waterways. Together with the 1936 congressional direction for the Corps to update 308 reports for important economic changes, new stream flow, and other resource data, this gave the Corps continuing authority for nationwide river basin planning for navigation and flood control. The 1936 Act also gave the Department of Agriculture responsibility for investigating watersheds and measures for runoff, water flow retardation, and prevention of soil erosion (American Public Works Association 1976).

The new flood control legislation also authorized investigations and surveys for many reservoir projects for navigation, flood control, and other purposes. Many basin-wide flood control plans were prepared and in 1938, following a series of catastrophic floods, construction projects were authorized for the Connecticut, Merrimack, Ohio, Upper Missouri, White, Arkansas, and Willamette Rivers (U.S. Department of Agriculture 1972).

Federal water resources planning continued through the war years, stimulated in part by an expected need for major public works to avert an economic slowdown after the war. State and local participation tended to fall by the wayside and eventually raised fears among western states of federal aggrandizement in water resources development. These tendencies and fears were allayed in Section 1 of the 1944 Flood Control Act. Section 1 established the principle of federal/state cooperation in planning for navigation, flood control, irrigation, and related federal water resource projects of the Corps and Bureau of Reclamation. All reports of these agencies henceforth would include state comments when submitted to Congress (Weber 1979).

The 1944 act also authorized a large number of new projects for many river basins "with a view to providing a reservoir of...public works for the postwar construction program." It also provided for integration of the Corps of Engineers Missouri River Basin plan for flood control and navigation ("Pick Plan") with Bureau of Reclamation planning for the basin which emphasized irrigation and hydroelectric power ("Sloan Plan"). The authorization for construction of the Pick-Sloan Missouri River Basin Project furthered full river basin development as a federally led activity.

Other provisions of the 1944 Act gave the Corps its first authorization to include municipal water objectives in multipurpose reservoir projects to supplement domestic and industrial water supplies. The Corps was also granted authority to build, maintain, and operate public park and recreation facilities, or to permit such construction and operations at reservoir sites, further broadening the multipurposes and benefits of water resource projects.

The 1944 Act gave Department of Agriculture responsibility to provide land treatments to reduce flooding for 11 watersheds covering 30 million acres. Disagreement between the House Agriculture and Public Works Committees kept these watersheds to a low number and excluded structural works. Implementation was divided between the Soil Conservation Service and the Forest Service. As the work began on these projects, it became apparent, as many experts had advised in past decades, that land treatment of watersheds alone, without water control structures, offered only limited flood protection (American Public Works Association 1976, U.S. Department of Agriculture 1972).

Increased Management of Federal Grazing Lands

The national forest grazing lands constituted about 100 million acres (area included under forests in table 1) which had been under professional management since about 1900. Progress had been made in rehabilitating their overgrazed condition and productivity. Increased stocking levels during World War I tended to halt, slow, or reverse the overall improving trend. Distressed cattle industry conditions after World War I, combined with stockmen's insistence on long term permits and resistance to sharp reductions and redistribution of stocking, tended to extend the slow rate of rehabilitation into the 1920's. Depression and drought during the 1930's also favored the cattle industry interests with retention of large numbers of cattle on national forests. Secretary of the Interior Harold L. Ickes' drive to have the national forest range transferred to Interior Administration and stockmen's organizational support to transfer the entire Forest Service to a new Department of Conservation tended to keep Forest Service grazing policies in line with the views and interests of the livestock industry (Rowley 1985).

Official publications of the Department of Agriculture for 1940 reported that national forest ranges improved 29% in productivity during the 1920's and 1930's due to good range management and conservation measures. However, other views inside and outside the Department indicated that increased stocking on some forests had actually damaged range resources. Progress thus

appeared to be mixed (Rowley 1985). A 1936 Forest Service study, The Western Range, reported that, on the average, the forested ranges of national forests were superior in condition compared with private and other publicly administered ranges. The ranges administered by the Department of Interior were rated in the poorest condition. This was largely due to the continuation of the open range policy on the 142 million acres of public domain and lack of any management until after 1934. The fact that most of the residual public domain lands were largely within desert areas of the nation with less than 15 inches of rainfall also contributed to their poor condition. The residual public domain was largely the land the homesteaders did not want because of their generally severe aridity (O'Callaghan 1969, U.S. Department of Agriculture 1984a, U.S. Senate Committee on Agriculture and Forestry 1936).

President Hoover offered the public domain grazing lands to the Western States early in his administration but without the mineral rights. The states, burdened with problems of the Depression, were unwilling to accept them without the minerals. The states' rejection opened the way for a new effort, the Taylor Grazing Act of 1934, to close the public domain after more than 20 years of frustrated attempts to bring order and management to the remaining 142 million acres of federal open range (Carpenter 1940, O'Callaghan 1969).

The act effectively closed the public domain to further settlement and created grazing districts for the management of the 142 million acres of rangeland. The districts were placed under the administration of the Grazing Service in the Department of Interior. The Grazing Service became the Bureau of Land Management in 1946, when its functions were combined with those of the historic General Land Office. The administrative aspects of this new federal program were similar to those for the national forest grazing permit system. However, far more decisionmaking power rested with the local advisory boards in each of the grazing districts (Rowley 1985). The stockmen were influential in bringing about this preferred working arrangement. In the 1940's, their influence was great enough to cut appropriations so deeply that even the basic administrative work of the grazing districts was supported by funds provided by the advisory boards (O'Callaghan 1969). In the same years, the Forest Service, apprehensive about the potential impact of World War II food demands on range stocking and range rehabilitation took a firm stance to resist pressure for increased stocking, and was largely successful in implementing this new resolve (Rowley 1985).

Minerals Management and Production

There was little change in the federal role in minerals management from 1920 to 1945. The physical volume of mineral production grew very slowly in the 1920's and most of the 1930's. With the onset of World War II in the late 1950's, however, production expanded sharply and then continued to grow after the war into the 1950's.

Ferrous mineral production actually declined after 1920 until the war demands substantially raised output. Coal production, measured in BTU's, declined even more and returned only to the 1920 level. It became a very troubled industry in the 1930's. Crude oil and natural gas BTU production expanded steadily by factors of 4 and 5, respectively, between 1920 and 1945. Oil and energy production and nonferrous metals and nonmetal mineral production likewise expanded steadily in this transition period (U.S. Department of Commerce 1975).

CROPLAND USE AND MANAGEMENT

Cropland use remained stable from 1920 to 1945, averaging 404 million acres a year (table 1). Farm population declined from 32 million to 24 million as the U.S. population rose by 34 million to 140 million. The number of farms declined 10% to 5.9 million. Their average size rose 30% to 195 acres (U.S. Department of Commerce 1975).

The trends in farm population, farm numbers, and farm size reflected a general increase in both farm labor productivity and average yield per acre. Total farm employment declined 25% from 13.4 million workers in 1920 to 10.0 million in 1945. Cropland used per farm worker increased from 31 to 41 acres indicating a significant improvement in labor productivity. The area of cropland used per capita for domestic food and fiber needs declined from 3.1 acres to 2.5 acres indicating about a 20% increase in average yields.

Most of the improvement in production efficiency came after the worst of the Depression had passed and during World War II. The accelerating adoption of the tractor as a replacement for horses and mules was the most important contributor to improving labor productivity. The Depression slowed the rate of adoption of tractors; but World War II demands, farm labor shortages, and the recovery of general farm prosperity rapidly raised the use of tractors and improved farm equipment to new heights. The number of animal work stock, horses, and mules declined over 50% with the increase of mechanical power (table 4).

During the 1920 to 1945 period, wheat yields increased about 30% and corn yields increased about 20%. Cotton yields increased even more. The increased applications of fertilizers and lime were indicative of factors influencing productivity. Commercial fertilizer use rose from 7 million tons to 15 million tons; lime use rose from 3 million tons to 23 million tons (U.S. Department of Commerce 1975). Most of the productivity increases came after 1935, partly in response to the agricultural stabilization programs, but mostly due to rising farm prices induced by World War II demands. Plant and animal disease control were improved. New plant strains and animal breeds were introduced. Hybrid corn came into use in this period. Danish hogs were imported to develop meatier hogs. Artificial insemination for dairy cows was used for more than 4% of the dairy herd (Rasmussen 1974, Schlebecker 1975).

Throughout the 1920 to 1945 period, the state cooperative extension services, editors of farm magazines, the

Table 4.—Animal work stock, farm machinery, and equipment, 1920 to 1945.

Year	Animal work stock	Tractors	Combines	Cornpickers	Farms with milking machines
	Thousands				
1920	25,742	246	4	10	55
1925	22,569	549	—	—	—
1930	19,124	920	61	50	100
1935	16,682	1,048	—	—	—
1940	14,478	1,567	190	110	175
1945	11,950	2,354	375	168	365

Source: U.S. Department of Commerce (1975).

Department of Agriculture, and other public and private institutions worked hard to bring the results of research and more productive technology directly to individual farmers. Local county extension agents, working on a one-to-one basis with cooperating farmers, became key catalysts in improving production and productivity. They not only aided the farmer, but also provided feedback to research. The results made it obvious that new technologies would bring major improvements in American farming. The depressed economic conditions and uncertainties of the 1920's and 1930's had been a major disincentive to innovation and productivity improvement. Nevertheless, many farmers were able to make significant gains in production efficiency in this period, especially as World War II demands raised economic incentives for greater production (Rasmussen 1974).

While total cropland used remained stable in this period, the location of production shifted significantly from the Eastern States and the Corn Belt to the Northern and Southern Plains, the Mountain States and the Pacific coast (table 5). About 30 million acres dropped out of production in the East while a similar amount was added to western production. The shift was facilitated by a 50% expansion of irrigated acres, from 14 million in 1920 to 21 million in 1945 (U.S. Department of Commerce 1975). Practically all of this expansion occurred in the 17 Western States. The shift reflected a large expansion of wheat production in the Western States and large acreage declines in corn production in the East and in cotton production in the South (U.S. Department of Agriculture 1942). In the West, the expansion was achieved largely through a conversion of rangeland and pasture to crop production (Frey and Hexem 1985).

Cropland agriculture achieved new records in total production in this period. During the war years, total crop production was 18% above that in 1929. Livestock production, including range and pasture production was 38% higher. Total farm outputs averaged 32% above the 1929 production level. Total farm output per unit of total input (i.e., overall farm production efficiency) rose 28%.[7]

[7]Estimated from table B-94 of Economic Report of the President, together with Annual Report of the Council of Economic Advisors (1986). Comprehensive farm output and input indices are not readily available before 1929.

Table 5.—Cropland used in United States by regions, 1920, 1940, 1950.

Region	1920	1940	1950
	Millions acres		
Declining			
Northeast	29	22	20
Corn Belt	90	77	81
Appalachia	34	28	26
Southeast	29	26	24
Subtotal	182	153	151
Stable area			
Lake States	40	39	41
Delta	20	20	18
Subtotal	60	59	59
Increasing area			
Northern Plains	80	90	96
Southern Plains	43	49	45
Mountain	20	29	35
Pacific	17	19	22
Subtotal	160	187	198
Total	402	399	408

Source: Frey and Hexem (1985).

Soil Erosion and Soil Conservation

Soil erosion continued to be a growing problem in the 1920's. A few scientists had accumulated a limited body of knowledge about the nature of soil erosion and its impacts. Severe erosion effects on farmlands were widespread and visible in many parts of the country. However, the national dimensions of the problem had not been assessed or described. Scientific data on how the soil erosion process worked and methods by which it could be prevented were very limited. American farmers still remained largely indifferent to soil erosion. They generally looked upon their eroding fields with great unconcern or did not recognize the losses that erosion produced. Productivity losses were often viewed as a natural reduction of the plant-food supply by the harvested crops (Bennett and Chapline 1928, Swain 1963).

Arousing national interest in conserving the soil in the 1920's was largely the work of a single individual, Hugh H. Bennett, soil scientist with the U.S. Department of Agriculture. His personal magnetism and scientific knowledge, based on more than two decades of soil study and research, farm demonstrations, publications, and lectures, made him "the champion of American topsoil" and the founder of soil conservation as a national concept and institution (Bennett and Chapline 1928). He was dedicated to developing an understanding of the causes, effects, and costs of soil erosion and defining effective ways to prevent, reduce, or control it at the farm level. In 1926, he prepared a plan for a series of 18 cooperative erosion experiment stations around the nation which generated strong policy support at the Department of Agriculture. That year the Department undertook an educational campaign about the seriousness of erosion. It also began to urge legislation for a full-scale study of the problem.

In April 1928, together with W. R. Chapline, Bennett published a very well illustrated circular, "Soil Erosion—A National Menace." It described some of the most serious areas of sheet and wind erosion and provided supplementary information on fertility losses, effects on sedimentation and flooding, variation by soil types, causes of erosion, and ways to prevent or control erosion. The circular pointed out that soil erosion was a national problem and menace. Bennett and Chapline reported "that some 15,000,000 acres or more of tilled land had been utterly destroyed by erosion in this country is but an insignificant part of the story, for it is the less violent form of erosional wastage, sheet erosion that is doing the bulk of the damage to the land" (Bennett and Chapline 1928). They doubted that the farmer alone would achieve the soil conservation work required to control erosion.

Bennett's persistent efforts were rewarded in 1928 with Congressional funding of $160,000 to study soil erosion from a national viewpoint. By mid-1932, 10 erosion experiment stations were gathering information. By early 1933, enough data had been collected to serve as a scientific basis for an effective program of erosion control (Swain 1963). During the same period of the early 1930's, the occurrence of prolonged drought in the Plains States led to serious and widespread wind erosion. The wind erosion damage was severe, dramatic, and highly publicized. A Washington newspaper aptly supplied the label "Dust Bowl" which captured and focused national attention on the drought, wind erosion, and farm hardship problems in the Plains (Helms 1981).

The convergence of conservation problems and the need to provide employment for one-fourth of America's young men who could not find jobs led to creation of the Civil Conservation Corps (CCC) proposed by the Roosevelt Administration and established by Congress early in 1933. The work of the CCC was limited to forestry, wildlife, and park projects, prevention of soil erosion, flood control, and similar projects on federal and state lands. A broad interpretation of the flood control objective, combined with a strong demand for CCC camps in states with few public lands, led to the establishment of 161 soil erosion control camps under the direction of the Department of Agriculture by 1934. Their work on private lands was limited to controlling gullies with soil-saving dams, planting trees and other vegetation, and building water outlets for established terraces.

In a parallel effort at the Department of Interior, Secretary Harold Ickes allocated $5,000,000 for soil conservation work under the authority of the National Industrial Recovery Act of June 1933. He also established the Soil Erosion Service (SES) and in September 1933 successfully recruited Hugh Bennett to lead the new agency. By linking public works funds for staff and supplies with labor resources provided by the CCC and taking both a whole watershed and whole farm approach to soil erosion control demonstration projects, Bennett was able to quickly demonstrate the potential of a well-designed and -directed soil conservation program. His approach reduced erosion while permitting farmers to continue farming without reducing income. Costs of conservation were largely borne by the public works funds, CCC camps, and cooperating farmers. Costs included money for seed, fertilizer, equipment, and labor to build terraces, waterways, and fences, and to improve pastures. Land too steep and erodible was converted to pasture or woodland to provide year round cover. On cropland, an appropriate mix of complementary structural and vegetative practices were tailored to the needs of each farm and farmer. Fields were rearranged to follow contour lines, planting methods were changed, and the use of cover crops was introduced (Helms 1985, Kelly 1985).

The Department of Agriculture, responding to concerns about organizational duplication and to Hugh Bennett's success, worked to secure transfer of the SES from Interior to Agriculture. In March 1935, President Roosevelt unified soil conservation programs by moving the SES to Agriculture. Drought and dust storms continued to emphasize the erosion problem in 1935. In April, while Bennett was testifying on soil erosion before a Senate Committee, the sky symbolically darkened with dust from the drought-stricken West. Later that month, Congress passed the Soil Conservation Act of 1935, declaring soil erosion as a national menace. Soil conservation thus gained a permanent commitment and became the responsibility of the Soil Conservation Service in the Department of Agriculture (Rasmussen 1981). This action also integrated and elevated the role of soil surveys in the implementation of the new federal conservation program at the farm level.

The National Reconnaissance Erosion Survey, initiated by the SES at Interior in 1934 under Bennett, was published by the Soil Conservation Service in 1935. It was the first comprehensive national assessment of the soil erosion problem. Survey maps for every county in the United States displayed the location, predominant character, and intensity of erosion conditions. The survey, together with previously assembled data, made it possible to estimate the actual extent and seriousness of erosion damage to the nation's soils resources. This information established the quantitative basis for the

nation's erosion control policy at the time (Miller et al. 1985). The significance of the new information is demonstrated by the change in Bennett's estimate of ruined or severely damaged cultivated lands from "probably not less than 10 million acres" in 1928 to "100 million acres," in 1935 (Miller et al. 1985).

In 1937, because of the high cost of research and developing federally financed demonstration projects, and with the need to reach all farmers, the Department of Agriculture shifted to a direct technical assistance approach to individual farmers. By 1947, all states had enacted enabling laws that established soil conservation districts as local governmental units for administering local conservation programs, aided by technical experts from the Soil Conservation Service (SCS) who would help farmers and district supervisors prepare and implement farm conservation plans, much as Bennett had done in the demonstration projects. There are now about 3,000 districts covering over 2 billion acres, including 1 billion acres on farms. The districts are managed locally and receive federal technical assistance from SCS. This institutional arrangement successfully linked local farm interests, state governments, and federal technical assistance in the prevention and control of soil erosion.

Direct financial assistance to farmers for undertaking conservation practices was initiated in 1936 through the Soil Conservation and Domestic Allotment Act. This act was designed as the constitutional substitute for the unconstitutional Agricultural Adjustment Act of 1933. The new legislation authorized rental payments for the withdrawal of cropland from production to promote soil conservation and provide a better balance between crop production and actual domestic demands. Participation was voluntary. Farmers were paid for diverting cropland to soil-conserving crops. Payments were also authorized for implementing soil-building practices on cropland and pasture. When this legislation was amended in 1938, payments for soil-building conservation practices were retained under the Agricultural Conservation Program and became a permanent part of the conservation incentives system of the Department of Agriculture. This program is administered locally by elected state and county committees under the general administration of the Agricultural Stabilization and Conservation Service of the Department of Agriculture. Prior to World War II, the program was used to divert land out of soil-depleting crop production. War demands then shifted federal efforts from reducing production to encouraging more production to meet expanding demands.

GRASSLAND USE AND MANAGEMENT

The grasslands declined from 750 million acres in 1920 to about 700 million in 1945 (table 1). The western ranges in this period declined by over 50 million acres while grassland in the 31 eastern states gained 10 to 15 million acres. The reduction in the West was due primarily to shifts to crop production, mostly wheat.

The total number of cattle, sheep, horses, and mules supported by these grasslands increased by 10 million. Comparison of this increase with the grasslands trend suggests that a small increase in overall grassland productivity accompanied the reduction in total grasslands. However, some of the improvement was due to an increase in the use of feedstocks to supplement grassland forage.

The largest increase in livestock use was for cows kept for milk. They increased steadily from 30 million to 41 million indicating some expansion of pastures in the 31 eastern states as cropland acres declined. Beef cattle increased by 5 million to 45 million. The number of sheep rose from 37 million in 1920 to 49 million in 1942, then dropped steadily to 40 million by the end of the war. Since five sheep are the equivalent of one cow in forage use, their increase was much less significant than the changes in dairy or beef cattle numbers. The decline in horses and mules released significant grassland capacity for cattle and sheep, both in the East and West (U.S. Department of Agriculture 1942, U.S. Department of Commerce 1975).

Management Progress on the Western Ranges

At the end of World War I, the stock industry, like other sectors of agriculture, experienced the hard realities of excess capacity, decline in livestock demands and depressed prices. The costs of indebtedness and operating expenses continued. Drought in the early 1920's, grasshoppers, prairie dogs, and crop and cattle diseases seemed to combine and add to the problems of the stockmen. Cattle prices in 1922 were less than 50% of their 1919 peak level of $45. They remained in that low range through 1926. Beef cattle numbers declined from 40 million in 1920 to 30 million in 1926. Sheep prices and numbers followed the same pattern to 1922 but began to recover earlier and more strongly than cattle (Clawson 1972, Schlebecker 1963, U.S. Department of Agriculture 1942, U.S. Department of Commerce 1975).

Ranch farming grew throughout the 1920's. Stockmen increasingly turned toward supplemental feeds to safeguard against losses from severe weather conditions, extend winter feeding periods, and provide supplements at other times. At the same time, wheat farmers of the North and cotton producers of the South tended to become cattlemen. Hay and other forage crop production increased; dams for water storage and irrigation expanded; pastures became common on farms, and millions of acres of wheat and other grain stubble were used for grazing. Several million tons of grain, cottonseed cake, linseed meal, and other concentrates were shipped into the range area for feeding. Ensilage, beet pulp, pea vines, bean straw, fish meal, rice, and fruit byproducts were also used as feedstocks. Ranch farming increased labor and other direct costs but it also reduced the general hazards of the cattle business and dependency on range forage. Ranch farmers seemed to prosper more than the crop farmers or the large herders. They intensified livestock management, used the range more effectively (often because there was less available), improved water facilities and supplies, and had fewer disease and weather losses due to better care of the

livestock. Predator losses were also reduced due to better control methods. Some cattlemen even turned to sheep as markets and prices for sheep recovered more rapidly than those for cattle (Schlebecker 1963, U.S. Senate Committee on Agriculture and Forestry 1936).

Beef cattle numbers dropped to a low level of 26 million in 1928. Cattle prices recovered and in 1929, they were close to the peak World War I levels. Wet seasons in the late 1920's, good feed, and heavy selling contributed to a clear understocking of the ranges. The western cattle business was healthy and prosperous once more.

As the cattle cycle turned up in 1929, the stock market crashed and the cattle market again fell into a rapid slump. Cattle numbers continued to rise to 36 million in 1934, but prices fell to the lowest levels experienced since the beginning of the century. Drought combined with depression. Cattle starved all over the Western Plains. Despite the apparent improvement in range management and conditions at the end of the 1920's, severe drought brought disaster to the cattle themselves. Some died because of lack of food, others due to dust on the feed. Still others died because stockmen were often unable to get food loans. Once again the 1930's dramatized the unpredictability of the greatest risks of the arid range cattle industry—weather and markets. The sheep industry experience with markets and prices in this period was similar (Schlebecker 1963, U.S. Department of Agriculture 1942, U.S. Department of Commerce 1975).

The nation's beef cattle herd once more declined to 30 million in 1939. Sheep declined to only 45 million after reaching 48 million in 1934. The stock industry received some relief from New Deal financial and conservation programs. Prices improved. Renewed prosperity returned in 1940 with the onset of World War II. The weather again improved except for scattered local droughts. The long term western water developments of the New Deal impounded water in reservoirs and ponds that in earlier times would have run off. Some ranchers were able to hold some water for the next year. Beef cattle prices rose to $54—their highest levels of the century—and beef cattle numbers rose to 45 million in 1945. Sheep prices did not fare as well, remaining well below the high prices achieved in 1917–20 and 1926–29. Their numbers again rose to 49 million in 1942 and declined thereafter (Schlebecker 1963, U.S. Department of Agriculture 1942).

The range use and development pattern of this period and the large expansion of the beef cattle herd that came after 1945 indicate that the low point in the condition of the western ranges was reached in the late 1920's. Although the drought of the 1930's no doubt delayed the rate of recovery, later developments and improved management on all lands indicate a turnaround had been made in the trend of range conditions. There were wide local variations around this general trend and vegetative conditions on the range were generally well below the grass conditions or climax cover type conditions before the 1860's.

THE USE AND MANAGEMENT OF FOREST LANDS

The forest lands of the United States increased by about 6% or 35 million acres between 1920 and 1945 (table 1). The rise was due in part to the natural regeneration of abandoned crop and pasture lands, primarily east of the prairies, to forest cover as they were increasingly dropped from farm production. Changes in use classification and improvements in accuracy of area estimates were other factors. There were also some shifts out of forest use for reservoir sites, rights-of-way, and urban uses (U.S. Department of Agriculture 1958).

Wood Use Trends

Industrial wood use continued a slow downward trend from the peak levels of 1906 and 1907. It dropped from 8.2 billion cubic feet in 1920 to 7.8 billion cubic feet in 1945. The lumber share declined from 66% to 62%. The pulpwood share, a growing industrial use, rose from 8% to 24%. Veneer logs and bolts rose to 3%. Minor products including cooperage bolts, poles, piling, fence posts, hewn ties, round mine timbers, and other assorted products declined from 25% to 11% of industrial wood use. Wood use as 1% of all industrial physical and structural materials likewise continued its decline from 33% at the beginning of the 20th Century to 25% during 1919–21 and 17% in 1945 (U.S. Department of Agriculture 1958).

The absolute and relative decline in lumber use (table 3) was due largely to the steady rise in lumber prices relative to other materials. The relative price index for all lumber more than doubled between 1920 and 1945. The basic cause for rising lumber prices has been attributed to lagging productivity in the lumbering industry. It did not keep pace with productivity growth in the general economy which had risen about 2% a year since 1850. An increase in the general level of wage rates forced the cost structure of the lumber industry upwards. This was the net result of two opposing factors. Technological improvements improved the mechanical efficiencies of logging, transportation, milling and remanufacturing equipment, and processes. This tended to reduce costs. Most of the progress in reducing costs, however, was offset by declining trends in size and quality of raw material and increasing distances between harvested forest areas and the nation's major population centers as the lumber industry moved increasingly further west (U.S. Department of Agriculture 1958, Zaremba 1963).

Fuelwood use also continued to decline and provided less than 10% of the energy supply in 1945. Fuelwood was largely limited to heating and cooking on farmsteads, fireplaces, and for generating heat and power from wood residues in some wood-processing plants (U.S. Department of Agriculture 1958). The slowly declining demand for wood products eased the pressure of timber harvesting on the nation's forest inventories in this period. Rising real prices increased the efficiency of wood utilization in end uses and provided a stronger incentive for forest management. The growing demand

for pulpwood also held the promise of shorter forest rotations and fuller utilization of wood growth. However, investment in the management of private and public woodlands was not yet seen as a generally profitable enterprise. Due to long rotations, calculated rates of return were low and risk factors were high. Over 20 million acres of forestland were still being burned annually in the early 1940's. Over 90% of the area burned was on private ownership, primarily in the South (U.S. Department of Agriculture 1942, 1958).

Commercial Forest Land Ownership and Timber Inventories

Forest ownership.—Commercial forests include those lands producing or capable of producing crops of industrial wood (20 cubic feet per acre per year or more) that are not withdrawn from timber use by law or administrative regulation. The ownership of commercial forests at the end of the 1920 to 1945 period is presented in table 6 for 1952, the earliest year for which consistent commercial forest land area and inventory harvest and growth data are available. The distribution of sawtimber inventories is shown in the same table. Sawtimber is used rather than growing stock since that was the predominant source of the timber harvest in this period.

The largest shift in ownership of commercial forest lands probably occurred between the public and private sectors. From 1920 to 1945, the Forest Service added 22 million acres to the net area of national forests. Most of the area added was in the East and acquired after 1933 by purchase under the Weeks Act of 1911. The acquisitions were the result of the New Deal policy to purchase farmlands in areas of low productivity where farming had become uneconomic and many farmers were liquidating their resources and often abandoning lands due to their inability to pay taxes. These acquisitions included some cutover timber lands from lumber companies in the Lake States and the South. States, counties, and local governments, which held about half of the area of other public commercial forests, acquired a large part of their forest lands through tax delinquency or purchase in the same period (Shands and Healy n.d.; U.S. Department of Agriculture 1920 and 1944, 1958).

Until about 1930, lumber industry ownerships tended to be largely temporary. They usually disposed of their timber lands by selling them for farming or other uses. They also often allowed cutover lands to revert to local governments through tax delinquency. Some lands were sold to the federal government or exchanged for public timber harvest rights. The latter practice had largely ceased by 1945. At the end of World War II, the prospects of higher prices, the benefits of capital gains taxation (extended in 1944 to timber harvested on forest industry lands), expansion of the pulp and paper industry's markets, and improving forest protection, particularly from wildfire, were beginning to raise the profit prospects for permanent forest industry ownership and management of forest lands. Between 1945 and 1953, pulp companies which could utilize small timber based on relatively short rotations of 25 to 35 years increased their holdings by 8.5 million acres while lumber company holdings declined by 2 million acres, mainly by transfer to pulp companies. From 1935 to 1945, the pulpwood harvest rose from 6 million cords to 14 million and then to 25 million cords in 1952. Over 70% of the pulp industry growth occurred in the South. Over 90% of the growth was based on the use of southern pine for pulpwood.

Forest inventory and harvest by ownership.—National forests held over 50% of the nation's softwood inventory. It was heavily concentrated in the West, particularly in the Pacific Coast states. Almost all of it was virgin timber. The average stocking level for all national forest lands exceeded 11,400 board feet per acre. Timber harvesting in national forests was a relatively minor part of the nation's timber supply during the 1920's and 1930's. Generally, federal timberlands were less accessible than private lands. As World War II raised timber demand from Depression levels, however, national forest timber sales in the 1940's rose to 3 billion board feet, primarily supplied by the West. The war needs opened up the demand for national forest timber sales which continued to escalate to more than 10 billion board feet a year after 1957.

Forest industry lands were concentrated in the commercially valuable softwood timber types that provided the bulk of the nation's timber supplies. Over half of the

Table 6.—Commercial forest land ownership and timber inventories, 1952.

Ownership class	Area		Softwood inventory		Hardwood inventory	
	Million acres	Percent of total	Billion bd. ft.	Percent of total	Billion bd. ft.	Percent of total
National forests	95	19	1,048	51	31	7
Other public	49	10	255	12	29	6
Forest industry	59	12	410	20	53	12
Nonindustrial private	296	59	353	17	333	75
Farm	172	34	—	—	—	—
Other	124	25	—	—	—	—
Total	499	100	2,066	100	446	100

Source: U.S. Department of Agriculture (1982a).

industry lands were in the South, with the balance equally divided between the North and West. Stocking per acre averaged 7,800 board feet, including the hardwoods that were located mainly in the East. The lower average stocking reflected the preponderance of eastern timber types and the relatively heavier harvesting that these lands experienced during the 1920 to 1945 period. A large part of the annual sawtimber harvest came from industry lands. In 1952, they provided 40% of the softwood harvest and 12% of the hardwood cut.

Over 90% of the nonindustrial private forest lands were located east of the prairies and divided about equally between the North and South. Only 8.4% were in the West. About 58% of these lands were attached to farms and owned by farmers. For the most part, they were heavily cut over in the 1920's and 1930's as well as earlier decades. Their average stocking level of 2,300 board feet per acre reflected that harvest history and a lack of any intensified management following harvest. Despite their heavy harvest history and low average stocking, they were supporting more than their proportionate share of the nation's timber harvest in 1952. Nonindustrial private forests were providing 39% of the softwood sawtimber harvest, about the same as industry lands, and 82% of the hardwood sawtimber harvest. These harvest rates as a percent of inventory were 4.2% and 3.2%, respectively. They compare with 3.8% and 3.4% on industry lands for softwoods and hardwoods, respectively, and 0.6% and 0.1% on national forests.

Other public forest lands made up the smallest shares of the commercial forest area and inventory. Their share of the softwood sawtimber harvest in 1952 was 6% and for the hardwoods, 3%. Their intensity of utilization and management fell between that of private ownerships and the national forests.

Forest Management

The most important need for improvement in forest management at the turn of the century was the yearly reduction in area of forest land burned. Forest fires destroyed regeneration and made reforestation a risky investment. They also destroyed the value of standing timber. Over 40 million acres of forest land were being burned annually in the 1920's (U.S. Department of Agriculture 1942, 1958).

The states with the largest timber inventories were among the first to organize protection systems. In the Pacific Northwest, lumber companies that had purchased large areas of heavily stocked virgin stands pioneered both private and state efforts to protect their timber values from fire. State agencies and private protection organizations paid less attention to burned and cutover lands since there was little investment being made on these lands for future timber production. In the Forest Service, the protection of the national forests became a high priority early and a standardized system of effective fire detection and control was being formalized in the early 1920's (Davis 1983; Robbins 1985; U.S. Department of Agriculture 1942, 1958). Even so, the annual burn in the late 1920's and early 1930's averaged a half million acres, over 3% of the total national forest area.

Forest protection improved notably between 1920 and 1945 on all ownerships. The total area burned in 1945 was reduced to about 20 million acres a year and the trend was down. One of the more significant federal actions was the passage of the Clarke-McNary Act in 1924 which increased federal matching grants to cooperating states for the protection of nonfederal forest land. It allowed for inclusion of private fire protection expenditures with state funds in determining the match, and thus granted an incentive to state and private entities to increase their protection efforts. By 1945, federal matching had increased to more than $5 million a year. However, one-third of the nonfederal forest lands still were not receiving protection (Davis 1983, Robbins 1985, U.S. Department of Agriculture 1958).

The downward trend in area burned reflected efforts of the Civilian Conservation Corps program of the 1930's, strengthened state fire control organizations, improved leadership by all agencies, and greatly expanded fire control facilities and financing. Total funding for forest fire protection had risen to $12 million in 1932. In 1952, it was more than 50% higher, measured in constant 1932 dollars. Federal support provided 43%, state funds 40%, and private funding the remaining 17%. By 1952, the annual area burned was less than 12 million acres, and 96% of that was occurring on private lands, almost entirely in the East. Two-thirds of the private area burned was in the South (U.S. Department of Agriculture 1958).

Tree planting on harvested forest lands or abandoned agricultural lands remained relatively low. In 1926, the total area of acceptable tree plantations was only 352,000 acres. Most of that was in the North. The annual rate of successful tree planting was only 68,000 acres during 1926 to 1929. It rose to 184,000 acres from 1940 to 1944. The total accumulative acres of successful tree plantations in 1944 was 3.3 million acres. Two-thirds of that progress had been made in the North. A good deal of the planting was accomplished in the 1930's under the stimulus of federal emergency conservation programs, including the Civilian Conservation Corps. The total plantable area in 1952 was estimated to be 52 million acres. Almost 22 million acres were in the South and about the same in the North, mainly on private lands. The remaining 8 million acres were in the West (U.S. Department of Agriculture 1958).

A great deal of unobserved natural regeneration was occurring on millions of acres of private farm lands that were being abandoned or taken out of crop production during the Depression and later years. Naturally regenerating pine stands on these lands were to become the new or second pine forest of the South in the 1970's and later. However, in 1945, the challenge to reduce the incidence of forest fires in the southern states was still there. Burning was still a socially condoned and established practice in the South for several purposes, even though the forest industry, the Forest Service, and state foresters had begun efforts to contain and restrain the traditional burning practices (Southern Forest Resource Analysis

Committee 1969). Perhaps indicative of the risks due to forest fires, southern forest industry planting on its own lands averaged only 6,800 acres a year from 1925 to 1945 (Williston 1980).

The Forest Service assessed the growth condition of recently cut stands for all ownerships in 1952. It was based on a sample of nearly 26,000 holdings in all ownership and size classes. The productivity index was based on four criteria that affect growth after cutting: (1) existing stocking; (2) prospective stocking in nonstocked or understocked areas; (3) species composition; and (4) age of the timber at the time the cutting occurred. Recently cut lands were classified into three productivity classes: upper, medium, and lower. Ratings are shown in table 7. They were applied to the areas of each ownership that were subject to recent harvesting. The aggregate area of these types was defined as the operating area (U.S. Department of Agriculture 1958).

The public and forest industry lands received the highest productivity ratings. About 80% of the area being harvested on these lands had very favorable conditions for regrowth following harvests. The farm and other private ownerships were reported to have the "poorest condition" and greatest need for management improvement. Productivity ratings were the lowest for these ownerships in the South. Holdings of over 50,000 acres in each private owner class received the highest ratings indicating very favorable conditions for regrowth after harvests. On the average, 78% of their operating area was ranked in the upper productivity class. Only 40% of the operating area of holdings less than 5,000 acres was rated in the upper class (U.S. Department of Agriculture 1958).

Within the forest industry ownership, the ratings for lands held by pulp and paper companies were the highest of any reported category; 84% of their operating area was reported in the upper productivity class. Pulp manufacturers owned nearly 40% of the forest industry lands (U.S. Department of Agriculture 1958).

Major Forest Policy Issues and Initiatives

During the 1920 to 1945 period, major forest policy issues focused on the management and protection of nonfederal forest lands. The Capper Report of 1920, prepared by the Forest Service for the U.S. Senate, was requested by Senator Capper in response to a Society of American Foresters committee report published in the Society's official Journal of Forestry in 1919. The committee, led and chaired by Gifford Pinchot, urged that the federal government regulate cutting practices on private timberland. The recommendation was predicated on a predicted timber shortage that would become a "blighting timber famine" within 50 years. The Pinchot report was the culmination of an intense debate which had been underway for several years in forestry circles over the question of federal regulation of private timber harvests. This committee report was seen by some foresters, especially in forest industry circles, as a threat to a cooperative approach to private timber harvesting that had been emerging since the Weeks Act of 1911 (Davis 1983, Robbins 1985).

Table 7.—Productivity of recently cut commercial forest land, 1952.

Ownership	Operating area	Proportion of operating area by productivity class: Upper	Medium	Lower
	Million acres	*-------- Percent --------*		
Public	96	80	17	3
Forest industry	44	77	19	4
Other private	42	52	28	20
Farm	53	41	37	22

Source: U.S. Department of Agriculture (1958).

The Capper Report emphasized that federal, state, and private forestry interests should cooperate to stop timber depletion. That was also the basic view of William Greeley, the Chief of the Forest Service. Although this and other policy views had been held and debated within the Forest Service, Greeley had developed, advocated, and supported such cooperation throughout his Forest Service career. The Capper Report took the position that the public had a responsibility to share in the costs of fire protection and to provide an equitable system of taxation for forest lands, their inventories, and growing stock. It made six recommendations: (1) increase cooperation with states in fire protection; (2) expand national forest areas; (3) study forest taxation and insurance; (4) restock burned and cutover federal lands; (5) provide for the periodic survey of forest resources; and (6) increase funding for forestry research.

The Capper recommendations were largely implemented by the Clarke-McNary Act of 1924 which amended the 1911 Weeks Act and emphasized a cooperative rather than coercive federal-private relationship. Timber production was included along with flood control as a justification for national forest land acquisition. It also authorized a comprehensive study of "the effect of tax laws, methods, and practices upon forest management." Other sections of the act provided for cooperative assistance for shelter belts, woodlots, and tree nurseries. The Prairie States Forest Project for planting a "tree" windbreak system to protect farm fields from wind erosion was administered by the Forest Service under this authority from 1935 to 1942 (Davis 1983, Robbins 1985).

The Forest Service undertook a decade long study of taxes, led by Fred R. Fairchild of Yale University, published as a report on Forest Taxation in the United States in 1935. The report argued that the annual property tax was essentially biased against investments with deferred yields (such as forest production), when compared to those with shorter term payoffs. The problem increased when high development values were assessed to forests. This view is still debated, but there seems to be agreement that property taxes levied on the full value of land and timber tend to reduce incentives for forestry relative to alternative uses. The ideas emerging from this study had an important influence in reducing property

tax burdens on forest lands through state legislation or reduced assessment procedures and thereby raising incentives for forest land ownership and management (Davis 1983, Robbins 1985).

The specific research and forest survey recommendations of the Capper Report were implemented by the McSweeney-McNary Act in 1928. The act greatly expanded the Forest Service forestry research capability by providing for establishing 11 regional forest experiment stations. It also authorized the systematic and continuous inventory of the nation's forest resources and directed the Forest Service to implement forest survey work in cooperation with state and private agencies. The forest survey objectives were to: (1) inventory forestlands and present supplies of standing timber and other forest products; (2) ascertain the rate of forest growth; (3) determine the forest drain due to harvesting and losses from pests and other natural causes; and (4) study future requirements for timber and other forest products.

The forest survey was initiated in 1930. It has since provided forest inventory information for individual states on a 12-year cycle. National summaries have been prepared about every 10 years with assessments of the long term outlook for timber demands and supplies. The information has become a valuable resource for the forest industry, states and many counties, and many landowners as well as the federal land management agencies (Davis 1983).

The idea of regulating forest practices did not fade away with the legislative responses to the Capper Report. The National Industrial Recovery Act of 1933, prepared with industry cooperation, provided for government control of production and price control. It also provided for formulation of forest practice rules by the forest industry based on the principle of industrial self-regulation, with states serving as the enforcement agencies. Industry support was conditioned by the excessive overproduction of lumber in the Depression years and depressed prices. This New Deal initiative, however, was aborted when the Supreme Court ruled the Act was an unconstitutional delegation of legislative authority (Davis 1983, Robbins 1985).

Federal regulation of private forest practices continued to be advocated within the Forest Service. Forest Service views on a possible program of public regulation for private forests were defined in the Copeland Report in 1933, prepared at the request of the U.S. Senate as a National Plan for American Forestry. It was an encyclopedic review of American forestry and forest industry conditions that contributed to the general forestry situation. Private ownership was defined as a dominant source of all the major problems of American forestry. A large extension of public ownership was advocated. All the major forest resources, timber, water, range, recreation, and wildlife, were addressed. Forestry research and the cooperative federal-state programs were also reviewed. Weak state and private commitments to forest management were sharply criticized. The Copeland Report complained that timberland owners accepted federal assistance to help them "shoulder a major part of the job of timber growing" but rarely did any management on their own. Nearly all states were enjoying some form of federal assistance but an inability to match federal funds reduced the impact of cooperative programs, particularly in the South where assistance was most needed.

Despite the criticism, the Copeland Report supported cooperation with the states and expansion of fire protection, insect and disease detection, and control; distribution of tree planting stock to industry and farmers at half-cost; expansion of extension forestry to farmers and industry; and expansion of forestry research. It also recommended a stronger direct federal role through the purchase of $50 million worth of private forestland annually and public regulation of logging on private lands.

The Depression and World War II preempted most of the potential impact of the Copeland Report. However, in 1935, Ferdinand A. Silcox, chief of the Forest Service, reopened the regulation issue with the declaration that "Public control over the use of private forest lands, which will insure sustain yield, is essential to stabilize forest industries and communities." He argued that private forest practices should be supervised by public agencies and not left to the forest industry. The idea was supported by the Forest Service leadership through the 1940's. It seemed to fade away as legislation proposed by Senator Clinton P. Anderson was discouraged by the opposition of the Society of American Foresters and the forest industry. That legislation approached public regulation of private forest practices through federal guidelines for state forestry administration.

Although the threat of federal regulation of forestry practices on private lands faded away, the issue produced some positive results. It raised incentives in the forest industry to employ scientifically-trained professional foresters, and to support state and federal efforts to improve forestry practices on private nonindustrial forestlands (Davis 1983, Robbins 1985, Wooten 1965). In subsequent years, various states enacted or promulgated voluntary forest practice standards for their private woodlands, often with forest industry cooperation. A few states such as California, Oregon, Virginia, and Washington enacted stronger regulatory legislation relating to harvest planning, harvesting practices, and reforestation after harvest. These initiatives have varied widely, both in their design and their results.

EVOLVING LAND USE FOR WILDERNESS, PARKS, WILDLIFE, AND RECREATION

Wilderness

As the national forest lands were expanding, the Forest Service developed its first official system for wilderness reservation with regulations for establishing primitive areas in 1929. By 1939, 75 areas encompassing 14.2 million acres of national forest were designated as primitive. In 1939, the original regulations for establishing wilderness areas were made more restrictive. By 1944, the Forest Service had reclassified and designated 4 areas totalling 1.4 million acres as wilderness. The rest of the 14.2 million acres continued to be classed as "primitive," pending reclassification (Hendee et al. 1978).

National Parks

The National Park System was largely a western system in 1920. Only 2 of its 37 diverse units were in the East—Acadia National Park in Maine and Hot Springs National Park in Arkansas. It continued to grow, and by 1933 there were 63 units, including 8 additions in the East. The latter included the Great Smokey Mountains and Shenandoah National Parks in the Appalachians, Mammoth Caves National Park in Kentucky, and Isle Royale National Park in Michigan (U.S. Department of Interior 1985b, 1985c).

During 1933, President Franklin Roosevelt added 53 new units to the system. His reorganization of the federal government consolidated all national parks, monuments, military parks, memorials, the National Capital parks, and 11 cemeteries under the National Park Service. Nearly 40 of the new units were in the East, mainly areas of historical and memorial interest. About a dozen predominantly natural areas from the national forests were added in the West. The addition of these units and the designation of the first national parkways and the first national seashore, Cape Hatteras, in the 1920 to 1945 period broadened the geographic scope and variety of the National Park System.

By 1945, there were 144 units in the Park System, totalling about 20 million acres within the contiguous 48 states. The Territories of Alaska and Hawaii had five additional units with several million acres. About two-thirds of the area of the National Park System was located in 30 national parks (U.S. Department of Interior 1985b, 1985c).

The National Park System was largely inaccessible to most Americans and only 6 million visits were reported in 1942 (U.S. Department of Interior 1985c).

State Parks

State efforts to expand state parks were very uneven in the 1920's. Activity was the strongest in the northern states from Maine to South Dakota and on the Pacific Coast. Very little progress occurred in the South or the Rocky Mountain and intermountain states. In the Depression years, however, the CCC camps were allocated to serve conservation needs in the Park System and at state parks. In the peak program year, 1935, there were 600 CCC camps—118 in the Park System and 482 serving state parks in almost every state. About 120,000 CCC enrollees and 6,000 professional landscape architects, engineers, foresters, biologists, historians, architects, and archaeologists were involved. Some states, such as New Mexico which did not have any parks, were able to establish them with CCC assistance. Others were able to advance the development of their state park systems. State park activity essentially stopped during the years of World War II. In 1950, there were 1,725 state parks with a reported area of 4.7 million acres, and total visits to state parks were reported to be 114 million (Davis 1983, U.S. Department of Commerce 1975).

Wildlife Management

In the 1920's and earlier, wildlife stocking, predator control, and protection of wildlife in reserves were the main approaches to habitat management and wildlife population rehabilitation. By 1945, habitats for 34% of the nation's larger wildlife species were protected in the national forests, national parks, and some 170 national wildlife refuges (Davis 1983).

States were improving and strengthening their game laws. In the early 1920's, an estimated 6 million sport hunters were licensed, compared to 3 million licensed hunters in 1910. Game laws became increasingly complex. The prohibition of night hunting, except for nocturnal game, was almost universal. Hunting and fishing seasons as well as creel and bag limits were greatly reduced. Fish and game law enforcement was increased. While there was clear progress in the restoration of wildlife populations, there was also debate and dissension about how best to manage them. Protection from predators and hunters did not always sustain populations. Some populations declined due to inadequate nutrition, disease, and fires. The Dust Bowl of the early 1930's was a disaster for waterfowl on the western prairies and plains.

In the early 1930's, Aldo Leopold published his classic Game Management, a text for professional wildlife management that altered the course of wildlife conservation. He recognized the role of legal protection for wildlife and provided a set of management principles to help maintain wildlife populations at optimum levels, consistent with man's requirements. Each species had its own seasonal needs for food, cover, water, and space. He addressed stocking levels, breeding potential, and habitat carrying capacity. The roles of limiting factors and hunting were also defined.

In 1934, Congress passed several laws designed to coordinate wildlife conservation on a nationwide basis. The Duck Stamp Act provided funds from hunting permits to purchase and develop wetland areas for a national system of migratory fowl refuges. A cooperative wildlife research unit program was established. It provided federal funds for wildlife research to be conducted by state land grant colleges with support from the state wildlife agencies and the American Wildlife Institute. The program began with 10 units and now includes 43 fishery, wildlife, or combined units in 31 states (U.S. Department of Interior 1984b).

The most far-reaching action of the 1920 to 1945 period was the passage of the Federal Aid in Wildlife Restoration Act, better known as the Pittman-Robertson Act (P-R Act) in 1937. The P-R Act authorized the allocation of revenues from the 10% excise tax on sporting arms and ammunition to the states for approved wildlife research and land acquisition, development, and maintenance. The P-R Act is particularly notable for its requirement that states enact enabling legislation prohibiting diversion of hunting license revenues to any use other than the administration of its fish and wildlife agency. It ended a common practice in many states of allocating fish and

wildlife agency funds to various public works not related to wildlife. The states used the P-R Act funds in the 1940's to develop and restock wildlife populations. Thirty-eight states acquired 900,000 acres of refuges and management areas. Deer, pronghorns, elk, mountain goats and sheep, moose, bear, beaver, and wild turkey were restocked (U.S. Department of Interior 1984a).

INSTABILITY AND TRANSITION END WITH AN UNCERTAIN FUTURE

The economic depression and adverse climatic conditions brought a good deal of distress to farmers, ranchers, and lumbermen as well as to conservationists and other interest groups during most of the 1920 to 1945 period. Resources were also stressed by the economic impacts of the Depression and adverse climate. Some reached the nadir of their transition in this period. Others suffered a slower recovery. A few successes such as the return of the white-tailed deer in the East, a major reduction in forest area burned each year, emerging increases in crop yields, and the growth and diversification of the National Park System brightened the resource picture. They were early indicators of the resilience of the nation's resources and their responsiveness to management and technology. Multipurpose water resource development brought the promise of improved protection against flooding. It also created a new basis for economic growth through expansion of low cost hydropower availability, better water transportation systems, and improved water supplies for irrigation and other uses to all parts of the nation.

New federal policies and programs lifted hopes for a better resource future, but the test of their effectiveness lay largely in the decades beyond 1945. World War II expansion of resource demands brought economic recovery to most resource owners and producers, but slowed the progress of many of the policies and programs planned for improving resource productivity and resource conditions. The end of World War II was welcome. It also presented an uncertain future for the nation's resources and new and unknown tests of the recently established policies and programs, emerging technology, and new management approaches as demands soon soared for all resource uses in the postwar period.

THE MODERN PERIOD OF RESOURCE MANAGEMENT AND USE, 1945–1985

From 1945 to 1985, the United States population rose by 100 million to 239 million. Total disposable real income increased 3.3 times while per capita real income more than doubled. General economic welfare and total domestic demand for goods and services increased more than 2.5 times. Agricultural exports nearly quadrupled. Agriculture and forestry generally prospered during this long period of economic growth (Economic Report of the President 1986).

In the 1980's, however, farmers and ranchers have again experienced economic distress as recession, reduced exports, and excess production depress markets and prices for agricultural commodities. Lumbermen have experienced the same distress as reduced housing starts and expansion of Canadian imports depressed lumber prices and profits.

As the population and economy steadily grew in this period, the use of land for urban development, transportation systems, parks and wildlife, and industrial purposes also expanded, from 180 million to 270 million acres (table 1). The total land available for crop, forage, and forest production declined correspondingly, by about 5%. Growth in population affluence, leisure, and mobility placed new demands on the nation's lands and resources for wilderness, wildlife, outdoor recreation, and related amenities including clean waters and clean air. Demand for natural resource products including minerals and fuels also expanded notably. These new pressures on the resources were largely met through productivity improvements, adjustments in land use, and a new emphasis on multiple use management.

Productivity, however, also rose, particularly for croplands, in response to expanding domestic and foreign demands for farm commodities. This reduced the pressure on land resources for more cropland. The production response, not only for crops but also for livestock and forest products, demonstrated a resilience of these long-used lands and resources that was neither planned nor clearly anticipated.

CROPLAND USE AND MANAGEMENT

Cropland used was about the same at the beginning and end of this period, a little more than 400 million acres. As production per acre grew faster than demands in the first part of this period, cropland shifted to other uses, leading to a decline in cropland use—to 384 million acres in 1969 (table 1). The acreage of crops harvested decreased even more, from 354 million acres in 1945 to 290 million acres in 1969.[8] After 1969, a rapid expansion in world demand and markets reversed the downward trend. The harvested crop acreage rose to a peak level of 366 million acres in 1981 in response to incentives provided largely by an expectation of continued growth in world demands, and price and income protection from federal commodity programs.

The portion of land used for crops continued to shift among the regions after 1945 but much less dramatically than during the 1920 to 1945 period (table 5). Cropland continued to decline in the Northeast, Appalachia, and the Southeast by 5 to 8 million acres in each region to 1982. In the Southern Plains, cropland use fell over 8 million acres to the lowest level since 1920. The only major cropland increase occurred in the Corn Belt where corn and soybean production expanded. In each of the other regions, the Lake states, Delta, Northern Plains,

[8] *Actual crop acreage harvested plus acreages in fruits, tree nuts, and farm gardens.*

Mountain, and Pacific, cropland used increased 1 to 3 million acres to 1982. Most of those small increases came after 1969 as exports increased.

Growth in Productivity

Indicative of the great increase in productivity, the persons supplied per worker rose from 15 to 77 (table 2). That trend applies to exports supplied abroad which was less than 2 persons per farm worker a year in 1945 and about 20 persons per farm worker in the early 1980's. Exports in 1980 made up 31% of total farm production including livestock, and 39% of the cropland output. Although exports fell sharply after 1980, they remained at high levels, accounting for 20% of total farm production and 25% of crop output in 1985. Export demands in the 1970's and 1980's became the single most important determinant of changes in cropland cultivated and harvested.

As productivity grew, farm workers declined from 10 million to 3.3 million (table 2). Farm labor dropped to 2.25% of the civilian labor force. Farm population declined at the same time from 24.4 million to 5.4 million, releasing enormous labor resources that largely became employed in other growing sectors of the national economy. Farm prices also declined relative to the general price level of all commodities, adding to the general consumer welfare.

Increases in farm productivity were a major source of the national economic growth in this period. As total farm output doubled, the mix and quality of farm inputs needed to achieve the increased production changed but the total remained constant. Productivity improvements in this way accounted for essentially all of the 40-year growth in farm production for both domestic consumption and foreign exports (Economic Report of the President 1986).

Factors Contributing to Productivity Growth

A number of factors combined to contribute to the spectacular rise in agriculture productivity in the postwar period. The most fundamental were the assurance of relatively high and stable prices provided by the commodity support programs, and strong markets in years the programs were not operative. These factors, together with crop insurance and natural disaster assistance programs, provided farmers an environment of assured rewards and reduced risk and uncertainty. Growth in domestic demands, combined with generally accelerating export demands, provided markets for a rising volume of production. When surpluses occurred, they were reduced or limited by acreage set-aside programs and government export programs which provided large volumes of food assistance at relatively low cost to developing countries in the latter 1950's and 1960's. Significant but lesser volumes of exports were donated to countries suffering major disasters. Often these export programs contributed to the later development of commercial markets for United States farm production in the recipient countries.

Another important factor contributing to productivity growth was availability of adequate farm credit for equipment, operating purposes, and real estate. A large part of the favorable credit supply was linked to reduced risk and uncertainty attributable to the federal farm programs and strong markets and market expectations. Inflation also assured cheaper money to pay off farm debts. Tax credits and other tax rules likewise contributed to a favorable environment for farm investment in new equipment, technology, and production. Low interest loans were also available from the Farmers Home Administration for those farmers who could not get credit from private sources (Farrell and Runge 1983, Paarlberg 1983, Schertz et al. 1979).

Underlying the favorable market and financial conditions was the experience with rising productivity in the late 1930's and early 1940's which provided an awareness of the potential to increase yields per acre, outputs per worker, and farm income with improved equipment and many other emerging technologies from federal, state, and industry research programs. The productivity potential of much of the new technology was enhanced by the development of new farming methods and systems combined with equipment innovations (Farrell and Runge 1983, Rasmussen 1974, Schertz et al. 1979, Schlebecker 1975).

In the 1970's, world crop shortages, a decline in the relative value of the dollar, and a strong world economy escalated world demands for American crops to unprecedented levels. The demands quickly absorbed American grain reserves that had been accumulating. High prices induced greater production and brought additional acres into cultivation. For most of the 1970's, commodity programs became inoperative since there was little or no need to limit or reduce production. In the 1980's, a world recession and a rising value of the dollar against other currencies reduced export demands for American crops; exports nevertheless remained at historically high levels (Farrell and Runge 1983, Paarlberg 1983, Schertz et al. 1979, U.S. Department of Agriculture 1984b).

The continuing and improving educational and information systems that brought the knowledge and understanding of new technologies to farm operators further contributed to productivity. These included the federal and state Cooperative Extension System, the great growth in farm journals and magazines, the expansion of industrial outreach activities to farmers as purchase of farm inputs was increased, and a significant increase in the average educational level of farm managers. These components of the information system often integrated and supplemented each other's efforts. Feedback from direct on-farm contacts and experiences with farmer problems and needs often contributed to more effective research and innovations. The proportion of farm managers with college degrees rose from 1% in 1940 to 10% in 1980; two-thirds also had completed high school compared to less than 13% in 1940 (Farrell and Runge 1983, Rasmussen 1974, Schertz et al. 1979, Schlebecker 1975, U.S. Department of Agriculture 1980a).

Farm productivity achievements in this short period have no comparable historical precedents in agriculture. They have been labelled the second American agricultural revolution (Rasmussen 1974). This achievement is of particular importance because it came at a time of rapid domestic and world population growth. The enormous increase in productivity and food production per acre had a beneficial effect in forestalling major shifts in land use from forests and grazing to crop production as domestic population and food demands nearly doubled. The expansion of food exports and American technology, likewise, probably slowed world pressures on the land and soil resources of many developing countries.

Farm Structure Changes

The same factors that encouraged the adoption of new technology and innovation in farming systems for productivity improvement also induced increases in farm size. As farm labor productivity rose, the farm operator was able to manage and cultivate more acres and increase farm income. Thus, as the number of farm workers decreased between 1945 and 1969, the number of farms declined 55% and average farm size doubled (table 8). The pattern was the same in all farm producing regions. The decline in farm numbers and increase in farm size continued after 1969 but at much slower rates. In 1982, there were only 2.4 million farms, 60% fewer than in 1945. The management of a billion acres of farmland, including cropland and associated grasslands and woodlands, was now in fewer hands.

Table 9 shows the number and distribution of farms by farm commodity sales classes for 1949, 1970, and 1982. In 1949, 79% of all sales production came from farms with less than $100,000 of gross sales, and they constituted 99% of all farms. Between 1949 and 1982, the percent of farms with $100,000 or more gross sales (1980 prices) increased from 1% to 12%. The number of farms providing this production rose from 50,000 to 302,000. Their share of sales rose from 21% to 69%. Thus, farm production and management became much more concentrated among fewer managers and larger farms (Harrington and Manchester 1985, Schertz et al. 1979).

With the increase in farm size, cultivated fields were also enlarged in order to capture the efficiencies of larger scale equipment. Farming became more specialized, again in order to capture the efficiencies of new technology. Farmers now purchase more of the inputs used in production and depend less on inputs produced on the farm. Since 1945, total farm labor inputs have declined about 80% while the farm real estate input has remained about constant. Mechanical power and machinery inputs have increased over 75%. Agricultural fertilizer, lime, and pesticides purchases have increased almost 10 times and feed, seed, and livestock purchases have more than doubled. Marketing and financial management have become a more significant aspect of

Table 8.—Number farms, acreage and size, 1945–1982.

Year	17 Western states	South	North	48 states
		Number of farms (thousands)		
1945	1,436	2,331	2,092	5,859
1969	808	864	1,054	2,726
1982	745	722	928	2,395
		Land in farms (million acres)		
1945	674	200	267	1,142
1969	690	154	215	1,059
1982	652	144	238	1,035
		Average farm size (acres)		
1945	469	86	115	195
1970	854	178	204	388
1982	876	200	256	432

Source: U.S. Department of Commerce (1975), U.S. Department of Agriculture (1942).

Table 9.—Approximate distribution of farms and value of production based on 1980 prices by farm sales class, 1949, 1970, and 1982.

Year	Over $500,000	$100,000–499,000	$40,000–99,000	$10,000–39,000	$1,000 9,999	Total
			Number of farms (thousands)			
1949	—	50	239	1,479	3,207	4,975
1970	16	190	566	690	1,413	1,875
1982	25	277	393	654	1,155	2,400
			Percent of farms			
1949	—	1	5	30	64	100
1970	1	6	20	24	49	100
1982	1	11	17	20	48	100
			Percent of sales			
1949	—	21	19	43	17	100
1970	22	32	30	11	5	100
1982	30	39	19	9	3	100

Source: Harrington and Manchester (1985).

farming, particularly on the larger farms (Economic Report of the President 1986, Harrington and Manchester 1985).

Technological Progress

Mechanization, the substitution of equipment for farm labor and animal power, continued to be the basic technology underlying the reduction in farm workers and increase in farm size. Table 10 shows the trend in equipment use from 1945 to 1983. The number of tractors continued to grow as farm numbers declined and size increased. As the number of tractors stabilized after 1965, their total horsepower continued to increase as the size and capacity of farm machines increased.

New and improved plant varieties, development of a wide range of pesticides to control fungi, insects, and weeds, and expanded use of chemical fertilizers substantially increased yields per acre. Crop production per acre doubled between 1945 and 1985 (Economic Report of the President 1986). Other factors contributing to productivity growth were the expanded use of irrigation, drainage of highly productive wetlands, double cropping, and the use of conservation tillage systems.

Irrigated croplands provide substantially higher yields than nonirrigated lands. They increased by about 30 million acres during the 1945 to 1985 period to 50 million acres. Only 10 million acres concentrated in the Southwest are associated with the extensive federal reclamation projects. The remaining 80% of irrigated lands are largely the result of nonfederal investments. In 1982, irrigated lands made up 13% of harvested cropland, but accounted for 32% of total crop value.

Corn, hay, wheat, and cotton made up 53% of irrigated acreage and 36% of irrigated crop value. Vegetable and orchard crops used less than 11% of irrigated land but produced 34% of total irrigated crop value (Hostetler et al. 1986, U.S. Department of Agriculture 1942).

The irrigated acreage grew about 7 million acres a decade from 1939 to 1969. In the decade following 1969, as export demands and farm prices rose, irrigation systems expanded by 12 million acres. The development of groundwater sources and movable sprinkler systems were important factors in achieving this expansion. Between 1950 and 1980, groundwater provided over 60% of the 82 million acre foot increase in water used for irrigation. It now provides over 40% of the 170 million acre feet used in irrigation (Hostetler et al. 1986). One-half of the irrigated acreage is in the 11 Mountain and Pacific Coast states and one-third in the 6 Plains states. The remaining 16% is in the East, where it has been expanded mainly to increase returns per acre and reduce risks due to local moisture shortages and periodic droughts (Hostetler et al. 1986).

The area of installed drainage systems remained stable during the 1920 to 1945 period at about 50 million acres. Most systems had been installed between 1900 and 1920. Between 1945 and 1980, the drainage systems increased to 110 million acres. About one-half of the 60 million acre increase was on wet soils and the other half on wetlands. The expansion of wetland drainage was most heavily concentrated in the Southeast, particularly in the Lower Mississippi Alluvial Plain, Florida, and North Carolina. Heavy wetland losses also occurred in Minnesota. About half of the wetlands converted to agricultural use were previously forested bottomland areas (Heimlich and Langner 1986a, 1986b). On a national basis, present wetland conversion rates are estimated to be about 300,000 acres a year, compared to an average yearly rate of 900,000 acres in the 1950's and 1960's. The lower current rate is attributed primarily to reduced drainage for agricultural use and secondarily, to various government programs that regulate or discourage wetland use (Office of Technology Assessment 1984).

Double cropping refers to the production of two crops on the same field in the same year. Rising prices and new technologies accelerated double cropping in the 1970's. Cropland double cropped rose from 3 million acres in 1969 to more than 12 million in 1982. About 44% occurred in the South, 32% in the North, and 24% in the Plains, Mountain, and Pacific states. Double cropping raises the productive capacity of cropland. In areas south of 40 degrees north latitude, for example, double cropping of wheat and soybeans raised per acre productivity 30% (Hexem and Boxley 1986).

Table 10.—Farm machinery and equipment: 1945–1983.

Year	Tractors	Total tractor horsepower	Combines[1]	Cornpickers picker/shellers	Pickup balers	Field forage harvesters
	Thousands					
1945	2,345	—	375	168	42	20
1955	4,345	—	980	688	448	202
1965	4,783	—	910	690	751	316
1970	4,619	203,000	790	635	795	331
1975	4,469	222,000	524	618	667	255
1980	4,775	277,000	669	690	764	301
1983	4,600	278,000	675	685	755	295

[1]*Data for 1975 and later are for self-propelled combines only.*
Source: U.S. Department of Commerce (1975), U.S. Department of Agriculture (1942).

Conservation tillage is a new farm production system, which reduces soil plowing and cultivation to a minimum, consistent with local soil, climate, and economic conditions. In general, it is any tillage system that leaves at least 30% of the surface cover as residue after planting. Typically, it relies more on herbicides and less on cultivation to control weeds. It is effective for many soil and climate conditions and suffers no yield disadvantage compared to conventional tillage with the moldboard plow. Conservation tillage became established in the 1960's and accelerated in the 1970's when energy costs were rising. Its rate of adoption has been faster than most any other practice in the history of farming. In 1983, 21% of all farmers who planted crops used some form of conservation tillage. In addition to cutting fuel and labor costs, conservation tillage also reduces erosion by as much as 50 to 90% compared to conventional moldboard plow tillage. It offers farmers the opportunity to save on costs of production and provides a low cost way to control erosion. In 1982, 100 million acres of cropland were under some form of conservation tillage (Crosson 1984, Rosenberry and English 1986).

Soil Erosion and Conservation

Local Soil and Water Conservation Districts were organized and operated in practically all rural counties of the 48 states through most of the 1945 to 1985 period. Technical assistance and conservation plans provided by the Soil Conservation Service (SCS) were available on a voluntary basis to all farmers who wished to participate. Cost share payments were similarly available under the Agricultural Conservation Program (ACP) of the Agricultural Stabilization and Conservation Service (ASCS) and the SCS Great Plains Conservation Program to finance implementation of conservation practices. The original ACP, established in 1936, had dual goals of encouraging conservation and supporting farm income. Over the years, the income support activities were phased out and those practices that are primarily production-oriented are no longer approved. The current emphasis is on long-term conservation practices and benefits.

Much of the serious erosion that was evident in the 1930's was healed with the help of these programs or by nature itself. Abandoned cropland and pasture usually regenerated to field and brush cover which often evolved to new forest cover in the East. Estimates of soil erosion on croplands declined from 3.6 billion tons in 1938 (Bennett and Lowdermilk 1938) to only 2.6 billion tons in 1967 (U.S. Department of Agriculture 1967).

In addition to conservation programs, several factors contributed to declining erosion. The total area of used and harvested cropland was at its lowest levels in the late 1960's (table 1). The number of farms had declined 50% and farm size had doubled. Farm tenancy was greatly reduced. Farm management had generally improved. Nearly 30 million acres of the more erosive cropland was withdrawn from cultivation for 10 years under the Soil Bank Program in the late 1950's and most of the 1960's. Under price support programs to reduce production, annual acreage reserves were required to be put into conservation cover crops (primarily grass). In the South, 2 million acres, planted to pine trees under the Soil Bank Program, added to the development of the South's Second Forest in the 1970's and 1980's. Drought was not a serious problem in the 1960's as it had been in the 1930's.

As large crop surpluses began to emerge in the mid-1950's and 1960's, conservation programs were criticized. They were seen as contributing to increased production per acre. Presidential budgets proposed elimination, reduction, or no-growth for conservation programs, especially in the case of ACP funding. As early as 1953, the Secretary of Agriculture tried to eliminate ACP cost sharing for production-oriented practices. Congress consistently supported conservation program funding and the authority of county and state committees and conservation districts to determine local county conservation practices and priorities. Nevertheless, the ACP level of assistance was gradually reduced by the impact of inflation on constant dollar funding. Technical assistance was reduced in the 1970's and the administration shifted program emphasis more to long-term conservation practices (Rasmussen 1981).

Persistent criticism became documented in a 1976 General Accounting Office (GAO) review and evaluation of the major agricultural conservation programs (General Accounting Office 1977, U.S. Department of Agriculture 1982b). It found that the major programs were falling short of their erosion control objectives. None were concentrating scarce resources on the most effective control measures, nor were they directing assistance to the farms that most needed help in reducing erosion. There was a lack of priorities for the most serious erosion problems. Subsequent agency evaluations confirmed these views. They reported that 52% of the ACP cost shares and 33% of conservation technical assistance for erosion control were being applied to lands where erosion was less than 5 tons per acre per year and generally not considered a conservation problem. Many critical erosion problem areas were not being effectively addressed (U.S. Department of Agriculture 1981c, 1985a). Congress, responding to the issues identified by GAO, enacted the Soil and Water Resources Conservation Act of 1977 (RCA). It directed the Department of Agriculture (USDA) to appraise the state of the nation's soil, water, and related resources and to prepare a program to further their conservation.

The RCA appraisal and program plan, involving nine USDA agencies and 34 different programs, was completed in 1982. For the first time, national conservation program priorities were established, and soil erosion control ranked first. It redirected funding to the highest priorities and established a policy for targeting critical erosion areas and other major problem areas. Focusing resources on critical problem areas became the general policy for increasing the effectiveness of national conservation programs. Strengthening state roles in conservation was also emphasized (U.S. Department of Agriculture 1982b).

As part of its soil and water appraisal work, the SCS conducts a National Resource Inventory (NRI). The first NRI was completed in 1977 and the second in 1982. In 1977, total cropland soil loss from water and wind erosion rose to 2.8 billion tons, slightly more than in 1967. About 2 billion tons of the loss was due to sheet and rill erosion, and the balance to wind erosion. The increase in total erosion was attributed to the increase in acreage of cropland used and harvested in response to export demands, and particularly to the substantial increase in row crop production. The total area planted to row crops rose from 145 million acres in 1969 to 170 million in 1974 and 195 million in 1980 (Fedkiw et al. 1981). Between 1975 and 1981, some 20.3 million acres were converted to cropland use, predominantly from rangeland, pasture, and idle lands. The new cropland had fewer conservation practices than existing cropland. About 10% of the converted acreage had wind erosion and 25% had sheet and rill erosion exceeding the acceptable limit of 5 tons per acre per year. The average erosion on all new cropland was 8.1 tons a year compared to 7.4 tons for existing cropland (U.S. Department of Agriculture 1985c).

In 1977, 77% of the cropland subject to water erosion was either nonerosive or managed with conservation practices that kept erosion within the tolerance level of 5 tons per acre per year (table 11). Thus, all the excessive erosion was concentrated on 22% of the cropland. Of the cropland eroding above the tolerance limit, 7% was so highly erodible that erosion could not be practicably reduced below the tolerance limit no matter what cropland management was applied. The total excess sheet and rill erosion was 1.3 billion tons and was concentrated on that 7% of the cropland where no type of management for crop production, except permanent grass or tree cover, would reduce it below the tolerance level. These data combined with geographic data indicated the erosion problem, though serious, was limited and not evenly distributed over the country. The RCA Program strategy, to focus resources for erosion control where the problem was most critical, appeared to be an effective response to the 1976 GAO audit and the findings of the 1977 NRI. Results from the 1982 NRI indicate that total erosion may have declined or possibly stayed about the same as in 1977. (The apparent decline may not exceed the sampling errors of the two inventories.)

Analysis of the 1982 data by soil loss and erodibility classes are closely consistent with table 11 data for the 1977 NRI. Both the total acreage harvested and the cropland used increased between 1977 and 1982. Thus, the NRI results for 1982 suggest that an increased allocation of conservation efforts to critical areas may have held the line on total erosion, even though total federal conservation funding declined 29% or $120 million in 1983 dollars. State, local government, and private funding initiatives offset about 20% of the federal decline. More importantly, their cooperation in focusing the federal program efforts on critical problem areas may have contributed even more to the effectiveness of 1982 programs.

State and local government awareness of soil erosion and related resource problems has been steadily enhanced by federal resource inventory and planning initiatives enlisting their cooperation. This includes the federal support for state assessment and planning for control of nonpoint sources of pollution from agricultural lands and other sources. State participation in the NRI and RCA planning processes have led to stronger state and local programs for erosion assessment and control. In 1984, 21 states offered cost sharing for conservation by a variety of formulas and mechanisms for a variety of conservation purposes including erosion control, nonpoint pollution and water quality improvement, water conservation, wildlife habitat, drainage, and farm, forest, and rangeland protection. In the 1960's, only one or two states offered such programs. Twenty-six states have given considerable regulatory power to the conservation districts. However, only a few states such as Iowa and Minnesota have chosen to exercise that power actively. A voluntary approach combined with economic incentives is preferred. Innovation in new state and local programs is increasingly evident. These initiatives vary

Table 11.—Cropland sheet and rill erosion by soil loss per acre and erodibility class, 1977.

1977 annual soil loss	Erodibility class: Non-erodible under any management	Manageable below tolerance	Managed above tolerance	Highly erodible	Total
Tons/ac/yr	Million acres				
Under 5	165	164	—	—	329
5–13	—	—	55	10	65
14–25	—	—	6	9	14
Over 25	—	—	([1])	11	11
Total	165	164	61	30	419
% of total	39	39	15	7	100

[1]*Less than 500 million.*
Source: Heimlich and Bills (1984).

widely among the states, reflecting their level of awareness of the dimensions of their erosion problem and their unique needs for soil and water conservation.[9]

The 1985 Food Security Act

The 1985 Food Security Act set the direction of farm policy and federal farm programs for the next 5 years. The 1985 Act introduces a transition toward a market-oriented agriculture based on world market prices. It does so by reducing loan rates and, therefore, the price support level for the major farm crops of wheat, feed grains, rice, and cotton. This is a major shift in policy away from the traditional programs designed to protect a depressed agriculture in its domestic market environment by assuring stable and high commodity prices. It is based on a new and wide understanding that the traditional policy is inconsistent with an export-oriented agriculture and a high and growing dependency on foreign markets to absorb rising production capacity. High domestic support prices under traditional programs encouraged expansion of production in other countries and greater competitiveness from other exporters. They also led to costly payments to farmers for income support and reduction of cropped acreage, for storage of surplus commodities, and for incentives to export more of the surplus.

This new orientation to world markets and prices calls for farmers to make improvements in productivity and reductions in unit costs their primary production strategy. In the competitive market of world trade, increases in productivity or a decrease in costs of production are translated into lower market prices. Growing demands, as world population and welfare rise, will be a source of upward pressure on prices. However, incentives to produce, combined with policies and incentives to develop and adopt new technology, will tend to keep production abreast of, or ahead of, demand. That is the usual outcome of successful competitive production.

This changing market environment will require farm managers to increase their attention to new developments in technology and innovation to reduce unit costs. It also means closer attention to market demands, markets, and prices for alternative crops and products. Financial and business management will become more important to farm enterprise success. There will be more large farms and fewer farmers. Because value of output per acre will rise even though prices may decline, there will be a stronger demand for soil conservation and coordination of efficient soil conserving practices with production operations. There will be long term pressures to concentrate farming on the most productive soils and lands and to avoid higher costs of cultivation on steeper and more erodible lands (Fedkiw 1986b).

The 1985 Act also set new policy directions for conservation programs. Congress integrated the objectives for conservation and commodity price support programs. Responding to the twin problems of excess crop production capacity and critical soil erosion, the 1985 Act authorized a long-term conservation reserve for as many as 40 to 45 million acres of highly erodible land that had been used to produce crops in any 2 of 5 years between 1981 and 1985. The program provides that farmers may sign contracts to withdraw eligible croplands from production for 10 years. In return, they will receive an annual rental payment and 50% cost share assistance for converting withdrawn lands to perennial grasses, wildlife plantings, windbreaks, or tree crops. The program goal includes planting 4 to 5 million acres of the reserve to tree crops. Data from soil surveys and the national resource inventory provided valuable information for defining cropland eligibility for the Reserve.

Cropland eligible for withdrawal under the 1985 Act includes soils considered too steep or shallow to farm in Capability Classes VI, VII, or VIII, and cropland in Capability Classes II to V eroding above the tolerance limit of 4 to 5 tons per acre per year for deeper soils and less for shallow soils. A total of 104 million acres of the 421 million acres cultivated in 1982 was eligible for participation (U.S. Department of Agriculture 1986f).

In 1986, the U.S. Department of Agriculture accepted bids to enter 8.8 million acres into the Conservation Reserve in 1986 and 1987. To maximize the effectiveness of the 1986 and 1987 contracts, eligible lands were limited to cropland eroding at least three times the soil erosion tolerance level or otherwise subject to gully erosion, and to cropland in Capability Classes VI, VII, and VIII. The average annual erosion on the 3.8 million acres withdrawn for 1986 was estimated to be 25 tons per acre. The total potential for erosion reduction through conversion to conservation cover crops was close to a billion tons a year. Some 8.2 million acres of the 8.8 million acres withdrawn was planned for conversion to grass. Tree crops were elected on 595,000 acres with 85% located in the southern states.[10]

The 1985 Act also made it federal policy to withhold eligibility for farm program participation and benefits from producers who convert wetlands to crop production after December 1985. Farmers who convert wetlands after 1985 may regain eligibility if they stop producing on those wetlands. Similarly, farmers who begin cultivation of highly erodible cropland after 1985 must certify that they are doing so under a conservation plan approved by the local conservation district to be eligible for farm program benefits. These requirements are referred to as the "swampbuster" and "sodbuster" provisions.

Another provision requires farmers who wish to participate in farm programs, and who were cultivating highly erodible land between 1981 and 1985, to plan and apply locally approved conservation plans. This cross compliance provision includes a grace period. Farmers have until 1990 to develop and begin to apply a conservation plan, and until 1995 to have it fully in effect (U.S. Department of Agriculture 1986e).

[9]*Information compiled and transmitted by the Appraisal and Program Development Division, Soil Conservation Service, U.S. Department of Agriculture by memo of June 19, 1986, to John Fedkiw.*

[10]*Current progress reports on Conservation Reserve Program implementation, Agricultural Stabilization and Conservation Service.*

These new policies discourage potential farm program participants from cultivating environmentally sensitive lands, or allow them to do so only with approved conservation plans. They affect about 80% of the nation's 2 million farmers who participate in farm programs. They also affect the use of 5.2 million acres of wetlands with high or medium potential for crop production, 118 million acres of highly erodible cropland in current use, and an additional 152 million acres of other lands with high or medium potential for conversion to cropland.

Other provisions of the Food Security Act of 1985 reduce incentives for farmers to increase yields and planted acreage primarily to increase farm program payments. Calculated historical average yields rather than actual yields are used to determine deficiency payments. Farmers are encouraged to plant less than the eligible acreage by an alternative that offers 92% of the program payments when as little as 50% of the eligible acreage is planted. The growth of eligible acreage over time is constrained in relation to past farm programs. In addition, conservation use is required for the nonplanted or diverted acreage. These conditions serve to reduce both the cost of farm programs and farm production while conserving cropland soils for other uses or crop production needed in future years.

MANAGEMENT AND USE OF GRASSLANDS

The total area of grasslands, unlike cropland, declined steadily throughout the 1945 to 1985 period (table 1), by more than 50 million acres. Total cattle numbers rose to the historic level of 132 million in 1975 and then declined to 105 million in 1986 (table 12). This was still 23% more cattle than in 1945 and 50% more than in 1920. More productive range and pasture management, reductions in grazing of other domestic animals, increased use of feeding, and improvements in cattle raising contributed to the ability of grasslands to support more cattle.

Growth of the Cattle Herd to 1975

From 1945 to 1975, the beef cattle herd increased from 16 million to 46 million head, or 177% (table 12). Dairy cattle numbers declined 60% in the same period. Growth in beef production came largely in response to growth in per capita beef consumption. It rose from 46 pounds per person per year, retail weight, in 1950–1952 to almost 95 pounds in 1976. Total beef production increased faster than population and per capita disposable income. The beef share of per capita red meat consumption increased from 38% to 46%. Beef production became a growth industry as beef became the strongly preferred animal protein source in the 1970's (Fedkiw 1985).

This was a period of general prosperity for cattlemen despite fluctuating cattle prices. Cattle numbers increased in 21 of the 30 years of this growth period. More than one-half of the increase in beef cattle occurred in the East where beef cow numbers increased 52% (table 13). Most of that increase came in the 11 Southeastern

Table 12.—Trends in total cattle herds, beef cows and milk cows 1945-1986.

Year	All cattle	Beef cows	Milk cows
	Million head		
1945	86	16	28
1950	78	17	24
1955	97	26	23
1960	96	26	20
1965	109	34	17
1970	112	38	13
1975	132	46	11
1980	111	37	11
1985	110	35	11
1986	105	34	11

Source: USDA, Statistical Reporting Service.

Table 13.—Beef cow herd by region, 1945-1986.

Year	11 Western states	6 Plains states	31 Eastern states	48 states
	Million head			
1945	4.6	7.1	4.8	16.5
1955	6.0	10.1	9.6	25.7
1965	7.3	13.2	13.7	34.2
1975	8.3	17.4	19.9	45.6
1980	7.0	13.9	16.1	37.0
1985	7.0	13.5	14.9	35.4
1986	6.7	12.6	14.3	33.6

Source: USDA, Statistical Reporting Service.

States which had over 25% of the beef cow herd in 1975. The six Plains states, including the Dakotas, Kansas, Nebraska, Oklahoma, and Texas, provided 35% of the increase in beef cows. The 11 western states shared only 13% of the increase.

The productivity of the ranges, forest grazing lands, and pasture increased during this period of growth. The improvement is indicated by the decrease in average acreage of total grasslands grazed (including forested range) per unit of all animals grazed. It declined from 13.7 acres in 1959 to 10.5 acres in 1974 (Boykin et al. 1980). The increases in beef production in the East and the Plains states were achieved with substantial increases in pasture lands. Between 1967 and 1977, pasture acreage increased 30% to 134 million acres of which 54% was on private lands. The shift of land out of crop production from 1945 to 1969 and some forest land conversion contributed to the net increase in pasture land. Cheap fertilizers encouraged the expansion of pasture production, particularly in the South (Fedkiw 1985, U.S. Department of Agriculture 1981b). The feeding of harvested forages and cropland residue grazing also increased in this period, mainly in the East and the Plains states (Boykin et al. 1980).

Many other factors contributed to increases in range and beef cattle productivity in this period, including

irrigation of feed crops, and expansion of hay lands and improved pastures. Sprinkler systems facilitated this trend. One rancher observed that a thousand acres of irrigated and subirrigated land was the equivalent of 16,000 acres of grazing land (Schlebecker 1963). Advances in biochemistry introduced many new technologies in the management of grasslands and cattle.

Plant hormones and herbicides such as 2,4-D and 2,4,5-T provided improved ways to control brush, cactus, and other undesirable plants. Antibiotics increased effectiveness in combating animal diseases. New systemic poisons made worm and insect control more effective. Animal hormones as well as antibiotics and tranquilizers were introduced to increase the rate of weight gains. Bacterial parasites and sterile male technologies were also used successfully to control insects (Schlebecker 1963).

Other advances in productivity came through better breeding of higher-producing animals. Artificial insemination of range cattle was used more intensively and worked more effectively as ranchers supervised their cattle more closely. Improvements in animal nutrition, feeds, and feeding were also important (Schlebecker 1963).

Along with prolonged favorable conditions in the beef industry, range conditions also improved. Range in excellent or good condition rose from 20% to 40% between 1963 and 1977. Range in poor condition declined from 40% to 18%. This was accomplished largely through the private sector, but with some assistance from USDA conservation programs (Fedkiw 1985, U.S. Department of Agriculture 1981b).

The Decline in Cattle Grazing to 1986

After 1975, cattle numbers started on a downward trend to 105 million in 1986 (table 12), with further declines expected in the rest of the 1980's (U.S. Department of Agriculture 1986d). Each of the major regions shared in this decline with a slightly larger share of the decline in the East (table 13). The drop in cattle numbers was directly due to a decrease in per capita beef consumption from 95 pounds in 1976 to 79 pounds in recent years. It is significant because it occurred while per capita disposable income was rising. The lower beef consumption is attributed to a sharp shift in consumer preferences to poultry products. The shift was associated with a sharp decrease in poultry prices relative to beef prices and growing consumer concerns about health and nutrition aspects of red meat consumption (Fedkiw 1985).

At optimum use levels, current forage capacity is estimated at 120 to 124 million head of cattle (Gustafson 1984). The meat industry is now seen as a mature industry. That is based on the fact that total per capita meat consumption has largely remained between 200 and 210 pounds since 1967. For mature industries, growth in demand is dependent upon population growth which is expected to average 0.7% a year in the next several decades (U.S. Department of Commerce 1985). Thus, current forage capacity appears more than adequate to meet future beef demands in the context of a mature industry.

In the meantime, results of the 1982 National Resource Inventory indicate that range conditions on nonfederal lands have remained stable or improved since 1977; 39% of the rangelands were in excellent or good condition and only 16% of the private grasslands were in poor condition.[11]

Federal Lands

The federal and nonfederal lands used for grazing in 1976 are summarized in table 14. Nonfederal lands are included for comparative purposes. They do not include improved pastures or cropland pastures which totaled 134 million acres and provided 54% of the grazing capacity. Harvested cropland grazed for forage is also excluded.

Some 90% of the federal grazing lands are located in the 11 western states where they are an important part of about 16% of livestock enterprises. In 1982, there were about 27,000 farmers and ranchers with permits to graze livestock on national forests or Bureau of Land Management (BLM) lands. They represented 2% of the 1.6 million cattle producers in the United States, about 10% of the total livestock forage grazed and only 2% of the total feed consumed by cattle. Federal lands provided grazing for these 27,000 producers in one or more seasons of the year when forage on their own lands or

[11]*See note 9.*

Table 14.—Federal and non-federal lands used for grazing, 1976.

Type of grassland	Forest Service	Bureau of Land Management	Other federal	Total federal	Non-federal
	Million acres				
Rangeland	58	145	8	211	418
Forested range	44	2	1	47	113
Total	102	147	9	158	531

Source: U.S. Departments of Agriculture and Interior (1986c).

from nonfederal rented lands was not available (U.S. Department of Agriculture 1981a, U.S. Departments of Agriculture and Interior 1986c).

Grazing use of both national forests and BLM rangelands was reduced between 1945 and 1965. The animal unit months (AUMs) grazed on national forests were reduced from 9.8 million to 8.0 million in 1965, or by 18%. National forest AUM use subsequently rose by 10% to 8.8 million in 1985.[12] On BLM lands, grazing declined more or less steadily from 17.8 million AUMs to 11.2 million in 1985, by 37%.

Reduced use and improved range management both contributed to improved range conditions on national forests. On BLM lands, progress appeared to come more slowly, partly because they were the most arid and, therefore, more difficult to rehabilitate and also because of the relatively poor initial condition resulting from a long history of uncontrolled free range use. From 1945 to 1975, BLM land in poor or bad condition decreased only 3%, from 36% to 33%, even though range use was reduced 33%. Range in excellent or good condition rose only 1% to 17%. Range in fair condition increased 2% to 50%. The BLM range condition was updated in 1984 based on professional judgmental estimation procedures and range inventory and monitoring data rather than direct sampling and measurement of range conditions. The results showed range in excellent and good condition rising to 36% and the proportion in poor or bad condition dropping to 18%. The difference in methods suggests that the more recent estimates may not be as reliable as earlier estimates, although the general trend toward more improvement is a realistic expectation (U.S. Department of Interior 1984c).

The expansion of outdoor recreation interests and activities and growing concerns about environmental quality stimulated an increasing emphasis on multiple use management of the public rangelands throughout the 1945 to 1985 years. This was particularly so on BLM lands where management was seen by the public as a single use orientation. The Multiple Use Sustained Yield Act of 1960 mandates multiple use management for outdoor recreation, range, timber, watershed, and wildlife and fish purposes for all national forest lands. The possible application of this principle to lands managed by BLM was visualized by the Classification and Multiple Use Act of 1964 (C&MU). Although the Taylor Grazing Act of 1934 had provided for management of the public domain lands, it had included the reservation "pending their final disposal," which clouded the management objective (U.S. Department of Interior 1984c).

The C&MU recognized that some of these BLM lands had multiple use values that ought to be retained under federal ownership and "managed...for grazing...fish and wildlife...industrial development...mineral production... occupancy...outdoor recreation...timber...watershed protection...wilderness...or... preservation of public values." The C&MU Act authorized BLM to gather data about the public lands and resources and provided that the Secretary of Interior determine which land should be retained. In 1976, Congress enacted the Federal Land Policy and Management Act, BLM's "Organic Act." It gave statutory recognition to BLM and authorized it to enter into long range planning and intensive resource management on the basis of multiple use and sustained yield (U.S. Department of Interior 1984c).

Stockmen with federal grazing permits maintained a strong economic interest in the use of federal ranges for grazing. While they generally resisted the policy for reducing the level of stocking, they often cooperated and assisted in achieving reductions where range conditions indicated the need to do so. The livestock industry generally perceived the shift toward multiple use management as a threat to traditional grazing privileges. Improved cooperative approaches to range management are now facilitating progress in multiple use management on federal lands. Pressures from conservation and environmental interests, however, continue to call for a stronger multiple use emphasis (Rowley 1985, U.S. Department of Agriculture 1986b, U.S. Department of Interior 1984c).

FOREST RESOURCE USE AND MANAGEMENT, 1945–1985

This period is typified by the rapid growth of demands for all the multiple uses of public forest lands. There emerged an unending debate about the proper balance of commodity production with amenity uses. The enactment of the National Environmental Protection Act in 1970 seemed to intensify this conflict as various interest groups found new ways to intervene in the management of public lands.

Large increases in lumber and plywood prices in response to rising housing demands and their contribution to the national problem of double digit inflation intensified efforts to find ways to increase timber supplies from public lands after 1970. There was also a continuing concern for improving the management of woodlands owned by farmers and other nonindustrial private forest owners who held 59% of all commercial forest land. Generally, timber growth and management performed better than projected, despite the increased timber demands placed on the nation's forest lands. The amenity use of the forests also expanded greatly. In 1985, it was apparent that the nation had not exhausted the capacity of the forests to further expand supplies for most of the demands on its resources. The conflicts, nevertheless, continued.

Land Ownership Shifts

Forest land increased somewhat as cropland continued to decline in the 1950's and 1960's (table 1). The trend reversed itself in the late 1960's when crop production rose again in response to rapid growth in export demands that continued through the 1970's and early 1980's. Urban and industrial development also tended to reduce the total forest land area after World War II. The net decline from 1940 to 1982 was about 6% or 35 million acres. The

[12] *Data provided by the Forest Service Division of Range Management for National Forests in memo dated 7/16/86 to John Fedkiw.*

decline in the commercial forest area segment, however, was just 17 million acres. In 1977, commercial forests totalled 470 million acres in the contiguous 48 states, about 82% of the total forest land (U.S. Department of Agriculture 1982a).

The shifts in use among commercial forests, agriculture, and other uses were much greater than the indicated net changes as illustrated in table 15. For four southern states between 1967 and 1980, for example, the total shift from forest to other uses was more than double the net decline of 2.5 million acres. The changes in land use associated with that net decline totalled 8.5 million acres. Nationally, between 1979 and 1982, about 11 million acres of forest and grasslands were converted to cropland use, while 4 million acres of cropland shifted to other use, for a net gain of 7 million acres of cropland. Thus, the dynamics of land use over time are far greater than the usually reported net changes.

The ownership of commercial forests also shifted after World War II. Forest industry lands increased by 9 million acres, mainly in the North and South where regenerated forests were still young and regrowth was rapid. Almost all the added acreage came from farm and other private ownerships. Total forestry industry lands were 69 million acres in 1977 with 53% in the South (U.S. Department of Agriculture 1982a). Farmer and other nonindustrial private ownerships declined by 18 million acres. However, this net decline included a reduction of 56 million acres of farmer-owned woodlands and an increase of 38 million acres in other classes of private owners. The decline in farm woodlands came with the reduction in number of farms and the decline in total farm land from 1.16 billion acres in 1950, the historic peak, to 1.05 billion in 1977. The decline in farm woodlands was 35 million acres in the South and 20 million in the North (U.S. Department of Agriculture 1982a).

Total public commercial timberland also declined in this period, from 144 million acres to 136 million. Three-fourths of the decline occurred on national forests, largely due to shifts of land to the wilderness system.

The Forest Inventory, Growth, and Harvest

The nation's softwood sawtimber inventory remained stable throughout this period at 2.0 trillion board feet. The hardwood sawtimber inventory rose from 0.4 to 0.6 trillion board feet. This favorable inventory increase in the last 40 years occurred even though the total industrial wood harvest averaged somewhat more than the historic peak achieved in the 1900 to 1910 decade (Davis 1983, Ulrich 1985, U.S. Department of Agriculture 1982a). Thus, the nation was able to meet its wood demands on a sustained yield basis, even though there were periodic projections and reports that such was unlikely with the level of forest management that was being practiced. Actually, periodic projections of future inventories since 1933 consistently underestimated both the growth and growing stock levels that the commercial forests achieved in the last 50 years. The low point in the standing volume of timber appears to have occurred between 1930 and 1940 (Davis 1983).

The current inventory is about one-third of the original volume at the time of colonial settlement. About one-half of the decline resulted from land clearing for farming and other purposes. The rest of the decline occurred on lands that remained in forest use and were generally regenerated to young, growing forests. Forests managed for commercial production achieve optimum net growth and yields with ages and inventories substantially lower than found in the original old growth forest heritage (Davis 1983).

In 1976, the annual growth of softwood growing stock was 12.3 billion cubic feet, 23% greater than the 10.0 billion cubic feet of harvest. Nationally, growth exceeded removals on national forests, other public ownerships, and farmer and other private ownerships. Harvests exceeded growth only on western forest industry ownerships. This was largely due to the rapid harvest of remaining old growth inventories on those lands. Softwood growth was greater than the harvest on industry lands in the North and South.

This favorable situation for softwoods has been projected to continue in the face of rising demands until the year 2000 or later, if forest management remains at pre-1976 levels. However, historic data indicate that management, as reflected in actual growth performance, does improve. Particularly important for softwoods is reforestation after harvest. Investment in tree planting is growing. Trees were planted on 2.7 million acres in 1985 (U.S. Department of Agriculture 1986a). That compares with

Table 15.—Changes in commercial forest lands in four southern states, 1967–80.

State	Net change in forest area	Diversions to Agriculture	Diversions to Other uses	Total diversions	Additions from Nonforest agriculture	Additions from Non-Commercial forest	Total added
	Million acres						
AR	−1.6	1.1	1.0	2.1	0.5	a	.5
FL	−0.6	0.5	0.8	1.3	0.3	0.4	0.7
MS	−0.4	1.3	0.5	1.8	1.4	a	1.4
SC	+0.1	0.1	0.2	0.3	0.4	a	0.4
Total	−2.5	3.0	2.5	5.5	2.6	0.4	3.0

[a]*Under 50,000 acres.*
Source: U.S. Department of Agriculture (1983).

1.9 million in 1976 and 0.5 million acres in 1940 and 1950. The outlook for further increases in reforestation is good. The opportunities for economic investment in managing softwood timber stands are extensive and more than adequate to increase softwood timber growth consistent with projected long term demands (Fedkiw 1983, U.S. Department of Agriculture 1982a).

Hardwood growing stock growth in 1976 was 9.4 billion cubic feet, more than twice that year's harvest of 4.2 billion cubic feet. This was a much more favorable management and inventory situation than for softwoods. Hardwood inventories have been projected to increase for a decade or two after 2000 despite expected rapid growth in hardwood demands. Although farmers and other nonindustrial private owners hold over 70% of the hardwood inventory, the favorable growth and harvest relationship occurs on all ownerships nationally. A hardwood quality problem was identified in the first half of the post-World War II period. However, Forest Service survey data and special studies show a significant general improvement between 1963 and 1977 in the hardwood log and tree grade inventory (Fedkiw 1983). Reflecting this trend, hardwood log, lumber, and plywood exports from the United States increased 3.4 times between the early 1960's and the 1980's. The United States became a net exporter of all hardwood products for the first time in the 1980's (USDA Forest Service 1986g).

Growth of the Nation's Demand for Housing and Timber

The nation's demand for housing rose sharply after World War II. Initially, it was largely a response to unfulfilled demands from the Depression and War periods. Rapid family household formation, home replacements, regional shifts in population distribution, and the rising economic welfare of the population added to the strength of that demand. The demand was enhanced by the Housing Act of 1949 which established national policy for housing and provided insurance from the Federal Housing Administration for level payment, self-amortizing, long-term mortgages, and mortgage guarantees from the Veterans Administration for war veterans to buy homes without any down payment. This mortgage protection increased the flow of capital into housing from commercial banks, savings, loan associations, and insurance companies (McKenna and Hills 1982). In the 1970's and 1980's, housing demands increased further and remained strong as the children of the postwar period began to form their own households.

Housing starts had averaged 360 thousand a year from 1930 to 1945, less than half that of the 1920's. Immediately after the War, they rose to 1.1 million a year. In the 1950's and 1960's, they averaged 1.5 million, and in the 1970's, 1.8 million, including 5 years with over 2.0 million units. The high interest rates of the late 1970's and the recession in the early 1980's brought housing starts to less than 1.2 million. In 1983, 1984, and 1985, they were again over 1.7 million a year (Economic Report of the President 1986, U.S. Department of Commerce 1966).

Annual softwood consumption was only 18 billion board feet during the 1930's. War demands and then housing starts raised consumption to 27 billion feet during the 1940's. In the 1950's and 1960's, softwood lumber consumption averaged 32 billion feet and in the 1970's, 37 billion. The 1980's raised consumption to 38 billion board feet; and in 1983, 1984, and 1985 when demands were strongest, average annual consumption was 43 billion feet (Ulrich 1985, U.S. Department of Agriculture 1982a).

Softwood plywood emerged as a new wood product for military housing during World War II. In subsequent years, it became a substitute for lumber sheathing in residential housing and other construction. Its consumption rose almost annually from less than 3 billion square feet in the late 1940's[13] to more than 16 billion square feet in the 1970's and 20 billion square feet in 1984 and 1985 (Ulrich 1985, U.S. Department of Agriculture 1982a).

Table 16 shows the growth in housing starts and softwood consumption, production, and net imports in cubic feet. Total supplies in the 1950's and 1960's increased

[13]*Based on 3/8-inch average thickness, 2.4 square feet of plywood are about equivalent to the volume of a board foot of timber. Thus, 2.4 billion square feet of plywood would be about equal to a billion board feet of lumber.*

Table 16.—Housing starts and softwood timber consumption, production and net imports, 1950–1983.

Year	Housing starts	Softwood timber[1]		Net imports	
		Consumption	Production	Total	Lumber
	Millions	*Million cubic feet, roundwood equivalent*			
1950–54	1.6	7.9	6.8	1.1	0.3
1955–59	1.4	8.3	7.2	1.1	0.4
1960–64	1.5	8.4	7.2	1.2	0.6
1965–69	1.4	9.4	8.3	1.1	0.7
1970–74	1.9	9.9	8.8	1.1	0.9
1975–79	1.7	10.7	9.5	1.2	1.1
1980	1.3	10.3	9.3	1.0	1.2
1983	1.7	10.4	9.7	1.7	1.6

[1]*Excludes fuelwood use.*

Source: Ulrich (1985), Economic Report of the President (1986), U.S. Department of Agriculture (1982a).

sufficiently to keep lumber and plywood prices at or below the general price level (table 3). As housing demands rose in 1969 and the 1970's to new heights, lumber and plywood prices rose sharply, from a relative price index of 100 in 1967 to 154 in 1978, 54% above the general price level for all commodities (table 3).

Hardwood lumber consumption has remained very stable since 1920; consistently averaging about 7 billion board feet a year. Average prices for hardwood lumber have stayed at or below the general price level since 1950. Total consumption of hardwood industrial roundwood increased from 2.0 billion cubic feet in the early 1950's to about 2.6 billion cubic feet in recent years. The net increase was due to the increased use of hardwoods for pulpwood. The production and consumption of hardwood roundwood for fuelwood rose spectacularly as energy costs increased in the 1970's, from 0.4 billion cubic feet in 1970 to 3.2 billion cubic feet in 1983 (Ulrich 1985).

Emergence of the National Softwood Timber Supply Issues

Softwood timber supplies became a national concern in the late 1960's and the 1970's. During this period, the rise in softwood lumber and plywood prices far outstripped the aggregate inflation rate. Softwood stumpage prices rose relatively more than lumber and plywood. Net lumber imports from Canada also rose to new levels (table 16). Thus, softwood sawtimber was again demonstrating the symptoms of economic scarcity on the supply side and raising the cost of housing.

Softwood timber supplies for housing became the subject of repeated national studies during the Johnson, Nixon, Ford, and Carter Administrations. The administration studies looked mainly to the large national forest inventories as the most effective source of greater timber production to reduce lumber and plywood prices and some of the general inflation. Nontimber interests in national forest use and management opposed and successfully resisted expansion of national forest timber sales. Two comprehensive legislative proposals for national forest management and financing were presented in Congress. Both had extensive hearings, but neither was passed. In 1974, the conflicting interests were able to agree on a systematic national planning approach to national forest use and management and other Forest Service forestry programs and Congress passed the Forest and Rangeland Renewable Resources Act of 1974 (RPA). Three 5-year RPA program plans have since been developed, in 1975, 1980, and 1985, and sent to Congress. Each set goals for long-term expansion of national forest timber harvests and other multiple uses. National forest timber sales and harvests, however, have remained at or below levels achieved in the early 1960's.

Continued opposition to timber harvests led to a successful court suit against clear cutting on the national forests. The ruling became an immediate threat to national timber supplies and quickly produced the National Forest Management Act of 1976 (NFMA). The new legislation responded to the court findings by clarifying the authority for clear cutting as an acceptable system of management. It also provided guidelines and a 1985 deadline for developing national forest land management plans based on "consideration of the economic and environmental aspects of various systems of renewable resource management...for outdoor recreation (including wilderness), range, timber, watershed, wildlife and fish...." The guidelines included opportunities for "public participation in planning for and management of the National Forest System."

National forest planning pursuant to NFMA now begins with the definition of public issues and concerns by various interest groups and individuals. That is followed by analysis of 8 to 15 management alternatives, each responding in some degree to the issues and projected resource demands. NFMA planning concludes with public review and comment on the resulting analysis and the Forest Service preferred plan. Using public comments and planning results, the Forest Service selects the alternative and plan that maximizes net public benefits subject to responding effectively to the issues. Final plans have been approved for 88 national forests. Draft plans have been released or approved for release for 34 forests. Only one forest is still in the planning stage in mid-1988.

The principal substantive legislation to emerge from Congress relating to timber supply was the authorization of two financial incentive programs to encourage tree planting on private lands. One was the Forestry Incentive Program authorized in 1973 and funded annually at $12 to $15 million for cost shares to nonindustrial private landowners. The other was the 1980 Reforestation Tax Incentives legislation that provided a 10% tax credit and a 7-year amortization for tree planting investments on private lands.

National Forest Management

The strongest demand pressure on national forest management after World War II was to expand timber supplies in response to the national housing needs. Annual timber harvests rose from an average of 2.8 billion board feet during the war years to 12.1 billion board feet in 1966, almost one-half billion feet a year. After 1966, timber sales ranged between 10 and 12 billion feet per year and harvests, fluctuating with economic conditions, ranged between 7 and 12 billion feet annually to 1984.

National forest sustained yield levels had substantially exceeded actual harvests during the war years. Thus, expansion was directed to increasing harvests on the individual forests to the allowable cut level or whatever portion of that level the market would take. In 1961, the Forest Service identified the long term sustained harvest potential of national forests to be 21.1 billion board feet by the year 2000. That included an intermediate goal of 13 billion feet in 1972 (U.S. Department of Agriculture 1961). The actual harvest in 1971 and 1972 averaged 12 billion feet. Timber sales volume, however, was only 10.5 billion feet.

The rapid rise of national forest harvests in the 1950's and early 1960's, largely in the West, was instrumental in maintaining a stable log supply for established mills and sustaining related jobs and income in the dependent communities. From 1952 to 1962, the western log supply from industry and other private lands declined 4.6 billion board feet (table 17). National forest harvests rose 4.5 billion feet. Harvest increases from other public lands modestly increased the total log supply. This performance, together with the increase in softwood lumber imports were important factors in stabilizing softwood lumber prices in the 1950's and early 1960's (table 3). They also contributed to a slowing of softwood sawtimber harvests in the South (table 17). Stumpage prices for southern pine sawtimber actually declined in this period.

Southern pine lumber production fell from 10 billion board feet in 1950 to 6 billion in 1960. Thereafter, southern lumber production rose slowly but did not exceed 10 billion feet again until 1984 (Ulrich 1985). The increased national forest harvest in this way contributed to the building of the southern pine sawtimber inventory in the 1950's and 1960's and the opportunity for expansion of sawtimber production to new levels in the 1970's and 1980's. The ability to balance harvests with timber inventories and age class distribution among public and private ownership classes over several decades was a major strategic achievement in a mixed economy. It reduced the pressures for more rapid industry and labor migration as well as demands for capital to build new plants in new locations. The national forest harvest increase thus added to national economic growth. It also produced a better distribution of forest age classes and management conditions for sustaining and increasing future timber supplies. This macro-aspect of American forestry has not been well understood despite the fact that it was a major management achievement.

The expansion of forest management for timber production required rapid development of the road system to provide for wide dispersal of sales areas and to access extensive forest areas for protection from fire, insects, and disease. The road system contributed to reducing the average annual area burned to 0.1% of the national forest lands. By 1960, the forest road system included 162,400 miles of forest roads plus 24,400 miles of public roads. This road access, combined with 106,500 miles of supplemental foot and horse trails, opened up a vast area of the national forests for public use for outdoor recreation, fishing, and hunting. In 1960, there were 92.5 million recreation visits. One-fourth of those were primarily for hunting and fishing. Hunters bagged 659,000 big-game animals, one-third of the big game taken in the entire country (U.S. Department of Agriculture 1961). The elk population increased from 154,000 in 1940 to 296,000 in 1960.[14]

As the demands for a wide range of outdoor recreation opportunities grew, national forest management responded to user interests. Landscape zones and travel zones were identified and management was modified to protect aesthetic values. Congress also began to designate National Recreation Areas. Throughout the 1950's and 1960's most of the response to growing user demands was achieved through land use adjustments. Those adjustments modified timber management plans and tended to reduce the timber harvest potential.

Multiple use management became a dominant principle in national forest management along with sustained yield. Both principles were formalized with Congressional enactment of the Multiple Use Sustained Yield Act in 1960.

National forest road construction in the year 1960 totalled 4,691 miles and rose to more than 6,000 miles in the latter 1960's (U.S. Department of Agriculture 1961). The acceleration of road development was perceived by wilderness interests as a threat to future allocations of national forest land to wilderness preservation in the West. By 1959, the Forest Service had formally designated only 12 areas and 3.9 million acres for wilderness preservation. The slow progress added to the concerns of wilderness interests, and between 1959 and 1964, the Forest Service accelerated wilderness reviews and designated an additional 42 areas and 5.2 million acres. Some 34 primitive areas and 5.4 million acres, however, still remained undesignated when Congress passed the Wilderness Act of 1964 which created a National Wilderness Preservation System to be made up of federally owned lands designated by Congress. The act also directed the Secretaries of Agriculture and the

[14]*Data provided by Division of Wildlife Management, Forest Service, U.S. Department of Agriculture.*

Table 17.—Softwood sawtimber harvest by region and ownership, 1952–1976.

	West					South	North	
Years	National forests	Forest industry	Other private	Other public	Total	All owners	All owners	Total
	Billion board feet							
1952	5.5	11.6	6.5	1.9	25.5	11.9	1.8	39.2
1962	10.0	9.8	3.7	2.9	26.4	10.9	1.4	38.7
1970	11.8	11.4	3.2	3.8	30.2	14.9	2.0	47.1
1976	10.3	12.2	3.0	4.2	29.7	18.9	2.2	50.8

Source: U.S. Department of Agriculture (1982a).

Interior to review federal lands suitable for Wilderness System designation by Congress (Hendee et al. 1978). By 1985, there were 327 designated wilderness areas on national forests totalling 32.1 million acres. Additional designations were being considered by Congress or under study by the Forest Service. Other wilderness areas had been designated or were under study on national parks and refuges and the lands administered by the Bureau of Land Management. In 1977, the total remaining roadless area potentially suitable for designation as wilderness areas was reported to be 145.5 million acres (Hendee et al. 1978).

Since 1960, national forest timber and range forage production has remained more or less stable. Mineral development and production, particularly for energy supplies, expanded in response to stronger domestic demands and prices. Congress provided for the designation of wild and scenic rivers in 1968, the protection of endangered species in 1973, and the preservation of historical and archeological sites in 1974 and eastern wilderness areas in 1975. These initiatives added to the multiple use management emphasis. In 1985, there were 20 wild and scenic rivers in national forests with a length of 1,154 miles and 12 National Recreation Areas totalling almost 2 million acres. There are 93 threatened or endangered wildlife species that have been identified on national forests. Two-thirds have recovery plans approved by the Fish and Wildlife Service of the Department of the Interior that focus on high priority species such as the rare Kirtland Warbler and the grizzly bear.

The largest increase in national forest use probably has been in general outdoor recreation. Recreation visitor days, based on 12 hour units of use by individuals, rose from 165 million in 1965 (when the visitor day unit of measure was adopted), to 225 million in 1985. One-third of the use was at developed sites such as campgrounds, picnic areas, ski areas, lodges, and visitor information centers. The remaining visitor activity was widely dispersed and dependent upon access to all parts of the national forests. Mechanized travel by visitors on the forest road system was the largest dispersed activity—50 million visitor days. Fishing, hunting, and hiking were the next most important activities totalling 44 million visitor days. Wilderness use was 12.5 million visitor days. The available forest area for wilderness use averaged 586 acres per visitor day, based on 150 days a year of accessibility of national forest lands for public use. The corresponding availability for all other recreation uses averaged 118 acres per visitor day. The capacity for additional recreation use is very large for most types of recreation.

Forest Management on Private and Other Public Lands

The most important management achievement on private and other public lands from 1945 to 1985 was the extension of the area protected from forest fires from 350 million acres to 340 million acres. The average area burned on protected and unprotected lands was reduced from 11.5 million acres before 1955 to less than 3.0 million acres after 1970. The area burned on protected lands was reduced from 3.6 million acres or 1.0% a year in the 1950's to 1.8 million acres or 0.2% between 1979 and 1983. This was largely accomplished through state protection organizations. Their annual expenditures rose from $132 million in constant 1972 dollars to $224 million. The federal financial assistance share fell from 25% to 7% by 1981. The Forest Service continues to provide general technical assistance and coordination for the state protection systems through its State and Private Forestry programs. The focus is on increasing the cost-effectiveness of state efforts (Fedkiw 1983, U.S. Department of Agriculture 1982a).

Tree planting has risen steadily since 1945 (table 18). Tree planting is primarily for reforestation of harvested lands, but also for afforestation of nonstocked lands that have previously been idle or used for crops or pasture. Practically all planting is for softwood species to obtain prompt regeneration with preferred species and to assure stocking with improved trees. Improved planting stock is increasingly being used for forest regeneration.

Most of the increase in planting has occurred since 1970 with slightly more than one-half on forest industry lands. The rise in industry planting is associated with an increase in both land ownership and harvests and with the economic advantage of prompt, planned restocking with improved nursery stock. The forest industry has been a major investor and supporter of research and seed orchard development for improved planting stock for all ownerships. Many firms have their own seed orchards and tree nurseries.

Tree planting on other public ownerships is low due to small forest area and the large proportion of holdings that are hardwood forests. Hardwood stands are usually regenerated naturally. National forest planting is a function of a more or less stable level of annual harvesting and a backlog of unstocked lands. The regeneration of the backlog is now largely completed, so national forest tree planting will mainly respond to the rate of harvesting.

Planting on other nonindustrial private lands has grown slowly and has seriously lagged the acres of softwood harvested on those lands. The high planting levels

Table 18.—Average annual tree planting by owner group, 1950–1985.

Year	Forest industry	Other private	National forests	Other public	Total
	Thousand acres				
1950–54	177	304	66	49	596
1955–59	319	794	97	81	1,291
1960–64	501	741	146	185	1,573
1965–69	549	429	133	251	1,362
1970–74	840	402	122	274	1,632
1975–79	1,093	454	291	129	1,967
1980–84	1,232	662	300	121	2,315
1985	1,441	885	255	113	2,695

Source: U.S. Department of Agriculture (1985d).

achieved between 1955 and 1964 were due to afforestation of farm lands, primarily in the South, under the Soil Bank Program. Those Soil Bank plantings began to contribute to the increase in southern harvests after 1970.

The 1979 RPA Assessment of forest and range land resources identified the lag in reforestation on nonindustrial private lands, particularly in the South, as a major cause of a projected shortfall in softwood timber supplies after 2000 (U.S. Department of Agriculture 1981a). Most of the recent upward trend in planting nonindustrial private lands is occurring in the South where 84% of all nonindustrial private reforestation was done in 1985. The federal forestry incentive program enacted in 1973 contributed to the 1975–79 rise in tree planting on these lands. A number of state and industry supported cost share programs introduced since 1970 have also contributed to the growth.

The softwood growing stock inventory on all ownerships increased 29% between 1952 and 1977. Nonindustrial private ownerships contributed 95% of that net increase. The hardwood growing stock inventory rose 47% in the same period with nonindustrial private lands adding 62% of the net increase. These growing stock inventory increases are indicators of the growing importance of nonindustrial private holdings to both the current and future timber supplies (Fedkiw 1983).

Long-term timber demand and supply projections show that harvests from nonindustrial private lands will be the major source of future increases in both softwood and hardwood supplies. The hardwood will come from forests of the North and South; the softwood harvests, largely from the South. The continuation of pre-1976 management intensities on nonindustrial private lands will not be sufficient to sustain supplies at the projected higher demand levels. Only about a third of the nonindustrial private lands being harvested presently receive professional forestry assistance. That does not appear to be enough (Fedkiw 1983; U.S. Department of Agriculture 1981a, 1984a, 1985b).

Timber prices will rise relative to the general price level, strongly for softwoods, but only selectively and generally slowly for the more abundant hardwoods. Although Canadian imports have driven softwood lumber and stumpage prices below their projected long-term trend in the last few years, it is unlikely that Canadian forest inventories and management can sustain the recent import levels. The outlook for higher real prices in the future should make new investments in improved forest management more attractive on public and private lands. The increase in planting on private lands since 1976 will contribute to the increase in softwood supplies, mainly in the South. It appears to have a momentum of its own. Tree plantations have been found to be more profitable than crop or forage production on some 17 million acres of marginal crop and pasture land in the South (U.S. Department of Agriculture 1983) where the Conservation Reserve program, authorized in the 1985 Farm Security Act, is accelerating tree planting on former croplands.

The task of improving management on nonindustrial private forest lands appears formidable in terms of its 8 million ownerships. However, three-fourths of the land area is held by only 8%, about 640,000 owners whose woodland holdings exceed 100 acres. This distribution pattern holds in the South, North, and West. A survey sample of harvested southern pinelands held by nonindustrial private owners found that 84% of the acres harvested were from ownerships with 100 acres or more woodland (Fesco et al. 1982). The efficiency of both logging and management rises as tract size increases to about 80 acres. Less than 40% of the harvested acres in this study received professional assistance for harvest planning or for reforestation. Harvests were determined by the logger or timber buyer on 35% of the harvested area and by the owner on 25%. The study found that owners had the right ideas about harvesting their lands but lacked site-specific knowledge to apply the most effective management. Loggers and buyers are interested in the profitability of their operations and generally do not have any long-term economic interest in the future productivity of harvested lands (Fedkiw 1983, Fesco et al. 1982).

The value of professional forestry assistance to private landowners was recently documented by a study of 40 ownerships with harvests in 20 counties in the Georgia Piedmont area (Cubbage et al. 1985). Half of the tracts received professional assistance with the harvest and management. On the other half, the owner or logger made the determinations. The assisted and unassisted tracts were paired within each county on the basis of similarity of conditions. Landowner characteristics within the two groups were also similar except for the employment of the professional services. The study found that landowners using professional assistance received 58% greater stumpage prices for the timber sold. Their residual stands were better stocked with desirable species for future harvests and would produce substantially greater future earnings. These benefits imply that forest landowners cannot afford not to use professional services in managing their tracts. The message, however, is not reaching the large majority of the nonindustrial private owners, including more than 60% of those with holdings greater than 100 acres. Effective educational and technical assistance, especially to help this latter group to learn the benefits of professional services, appears to have a high potential for success in improving the management, productivity, and earnings of the larger private holdings.

The Role of New Technology in Forest Management and Productivity

New technology has been one of the most significant factors in extending and increasing timber supplies and improving forest productivity. It has made it possible to utilize practically all timber species for commercial products. Research developed the original pulping processes, then the various ways to pulp hardwood species of all densities, and substitute them for the scarcer and more expensive softwoods. It also found ways to utilize wood residues from both softwood and hardwood lumber and

plywood mills for pulp production. As prices of lumber rose relative to pulpwood, chip-and-saw equipment was introduced to chip the exterior of pulp logs while retaining interior squares for the more valuable lumber stock.

Softwood plywood and particle boards have substituted for sawn lumber boards. More recently, wafer boards, flakeboards, and oriented strand boards have provided panel stock with the strength qualities of plywood and ability to utilize the lower grade and lower cost hardwood species in place of more expensive, higher grade, softwood sawlogs. New processes now also use lower grade hardwood logs to produce high quality hardwood cuttings and blanks for the furniture industry. Emerging dry press pulping technology makes it possible to substitute lower value, more abundant hardwoods for the vast quantities of southern pine timber used to make liner board for the freight packaging industry. We are in a period of abundance of new and emerging technology in wood utilization and wood products whose benefits of improved timber supplies and reduced costs can be captured rather swiftly. These new technologies have important implications for forest management as well as forest industry. Utilization rigidities associated with specific species will be reduced together with related geographic constraints on sources of supply and plant locations which should reduce transportation and marketing costs, lower product prices, and give a boost to total wood demands. Requirements for large tree sizes and longer rotations should be reduced which should bring savings in the capital costs of holding larger volume managed timber inventories. The impact of new technology has been reflected in timber demand and supply projections insofar as it can be credibly visualized and predicted, but it is difficult to convert the potential impact of new technologies into a reasonable trend type projection.

MINERALS USE, PRODUCTION, AND LAND MANAGEMENT

U.S. Use and Production

World War II mineral needs marked the beginning of a rapid increase in the demand for all minerals in common use after 1945. The postwar surge of research in many fields also brought significant changes in technology and many requirements for new mineral materials. For the first time in American history, consumption of nonfuel minerals began to rise more rapidly than production. By 1979, imports exceeded exports by more than $2 billion (1967 dollars) and in 1984 and 1986, the value of net imports of nonfuel minerals exceeded $6 billion (Cameron 1986, Dorr n.d.). The pattern was similar for mineral fuels. Production rose from 31 quadrillion BTUs in 1945 to nearly 65 quadrillion BTUs in 1985. Consumption rose from 30 quadrillion BTUs to nearly 75 quadrillion BTUs in the same time period (U.S. Department of Commerce 1975, 1976, 1984).

Increased dependence on net mineral imports is an indicator of economic scarcity. It is in large part the result of deficiencies in production of minerals and fuels from domestic mines and mills. Mine production of metals peaked in 1970 and then declined, though somewhat unevenly. In 1984, U.S. dependence on imports exceeded 50% for 21 out of 32 important nonfuel mineral commodities evaluated (Dorr n.d.). This dependency ranged from 9% for aluminum to more than 90% for columbium, sheet mica, strontium, manganese, bauxite and alumina, cobalt, tantalum, fluorspar, and the platinum materials group. Imports dependency was 23% for iron and steel and 19% for iron ore.

For mineral fuels, the U.S. went from virtual self-sufficiency in the 1940's and early 1950's to about 15% dependency on imports in the early 1980's as measured by BTU production and consumption. That dependency came entirely in the petroleum resource area where import dependency rose to about one-third in the early 1980's. As dependency on petroleum imports rose, coal production (mainly bituminous), increased from an historic low of 22% share of BTU production and a 17% share of consumption in the early 1970's to 29% and 22%, respectively, in the 1980's (U.S. Department of Commerce 1976, 1987).

Deficiencies in U.S. production arise from the lack of economic deposits of some minerals such as sheet mica, tin, and diamonds. In other cases, it is the depletion or exhaustion of high-grade ore deposits as in the case of iron ore. Very large reserves of low grade iron ore remain and some are being mined. Imports of higher grade ores and concentrates, however, are increasing. Even though U.S. production and consumption of minerals rose notably in the postwar period, its share of world production declined from 23% in 1950 to 11% in 1980; its share of world consumption fell similarly from 25% to 13%. Improved world supplies relative to U.S. supply potentials also contributed to domestic production deficiencies. Because mineral processing involves the handling of large volumes of material and great weight reduction, the smelting, refining, and processing capacity tends to locate near major new mineral deposits. For example, most of the new alumina and aluminum plants are being built in places like Brazil, Venezuela, and Australia where the large world reserves of bauxite are located. For the same reason, new ferrochrome plants in South Africa, Zimbabwe, Brazil, and India are supplanting American plants (Cameron 1986, Dorr n.d.).

Analysis of price trends for minerals indicate that the prices of many important minerals and fuels rose relative to the general price level after 1970, another indication of economic scarcity. This was a reversal of the general trend for the preceding 100 years when the relative prices of minerals and fuels were generally stable or declined. The economic scarcity interpretation, however, has some weakness because the rise in mineral and fuel prices after 1970 also reflected the rise of the exchange rate against the U.S. dollar, OPEC actions to raise oil prices, and higher costs of mineral activities associated with environmental and land management changes after 1970. Through 1983, the price evidence on economic scarcity is not totally convincing (Myers and Bennett 1985).

Nevertheless, the U.S. mineral position is viewed as weak for a number of important metals. Considering known reserves, this position is expected to become progressively and significantly weaker through 2005. The solution is seen to be in the discovery and development of new, economically productive deposits and expansion of reserves. The western states and Alaska, where federal lands are extensive, reportedly have the potential for large contributions of lead, zinc, copper, molybdenum, and perhaps tungsten, mercury, antimony, and nickel. Exploration for metals other than gold or silver, however, is virtually at a standstill (Cameron 1986).

Land Management

Generally, the postwar growth, land use and management, and legislation and administrative regulation at the federal, state, and local levels have acted to withdraw and restrict access to public lands for mineral exploration and have added to the difficulties and costs of exploration and development (Cameron 1986). Regulation is directed toward environmental objectives, protection of the surface uses and benefits (including the environment), and to eliminate abuse of the mineral laws. For the most part, the land use and management legislation and administrative law came after the passage of the National Environmental Protection Act in January 1970.

Subsequent federal legislation which affected the complexity of and access to mineral exploration and development included:

- Clean Air Act and Amendments of 1970;
- Clear Water Act of 1972;
- Endangered Species Act of 1973;
- Forest and Rangeland Renewable Resources Planning Act of 1974;
- Toxic Substance Control Act of 1976;
- Federal Land Policy and Management Act of 1976;
- National Forest Management Act of 1976; and
- Surface Mining and Coal Reclamation Act of 1977.

Prior to 1970, the Wilderness Act of 1964 provided authority for major federal land withdrawals for a National Wilderness Preservation System. By 1988, almost 90 million acres had been designated by Congress and additional acres were being considered and studied. Any lands not claimed or leased for minerals were closed to entry after 1983. However, data collection, including prospecting for minerals and other resources, is permitted—providing the activity is compatible with wilderness preservation. But, subsurface exploration for effective assessment of "hidden" mineral deposits appears to be largely foreclosed and effective exploration for operability is practically precluded. Theoretically, Congress can withdraw areas from wilderness status for mineral purposes, but that seems unlikely unless there is positive evidence of a significant mineral deposit. These circumstances are seen as seriously circumscribing mineral exploration and development in wilderness areas, even though information gathering and prospecting are permitted (Cameron 1986).

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) established a federal and state regulatory framework to prevent resource abuses that had characterized surface coal mining. It pertains to both public and private lands. Similar laws in states such as North Dakota, Wyoming, Colorado, and Montana preceded SMCRA in the late 1960's and early 1970's, when western states were anticipating an increase in demand for coal and a need to control the environmental effects of coal mining. SMCRA is implemented mainly through state legislation and regulation no less stringent than the Federal Act. Permits and performance bonds to assure reclamation are required of all operators engaging in coal mining. Performance standards, inspections, and penalties are also included. SMCRA also provides for reclamation of abandoned mine lands estimated at 1.1 million acres at the beginning of the reclamation program. This program is funded by fees paid by permitted coal mine operators on each ton of coal mined. Total fees collected for reclamation through early 1988 exceeded $2 billion. Permits issued for mining and reclamation operations in the past 10 years exceed 25,000 and affect over 3.4 million acres (Office of Surface Mining, Reclamation, and Enforcement 1987).[15]

Congress also passed a Mining and Minerals Policy Act in 1970 to address environmental issues. Its purpose was to foster and encourage private enterprise to develop economically sound and stable domestic mining and mineral industries and the orderly development of domestic mineral resources. Unlike the positive response to the environmental legislation, little was done to achieve the purposes of the 1970 Mining and Mineral Policy Act and no grassroots constituency developed to address issues in the mining area (Dorr n.d.).

Ten years later, Congress passed the National Materials and Minerals Policy, Research and Development Act of 1980 in response to mining industry concerns with the increasing restrictions to explore for, develop, and produce minerals on federal land which constitute about one-third of the U.S. land area. It was also a response to expressed concerns about potential shortages of critical and strategic materials should foreign sources for supply be disrupted. The 1980 Act declared it to be national policy to promote an adequate supply of materials and to consider "a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs" (Dorr n.d.).

The President transmitted a National Materials and Minerals Program Plan and Report to Congress in 1982 as required by the Act. The Bureau of Land Management is developing an Automated Land and Mineral Record System in response to the report sections addressing data collection and land availability. The objectives of this automated public lands information system are to define: which federal lands are held under the 1872 mining law, which are leased, which are withdrawn from location or leasing or both; which are open with restriction and

[15] *Personal conversation with Bobby Rakestraw, Soil Conservation Service, U.S. Department of Agriculture, Washington, DC.*

what types of restriction apply; how much and which land the federal government owns, where it owns surface rights but not subsurface or vice versa; and where jurisdictional responsibilities overlap and where regulations conflict (Dorr n.d.).

PARKS, RECREATION, AND WILDLIFE

Parks and Recreation

After World War II, public visits to the National Park System increased to 50 million by 1950 and 72 million by 1960. This trend paralleled the increase in visits to the National Forest System. Expanding use made park maintenance and development projects, deferred during the war, a new priority for the National Park Service. The major response was Mission 66, a 10-year rehabilitation and capital development program begun in 1956. The goal was to improve the System's facilities and resource preservation for the occasion of its 50th anniversary in 1966 (U.S. Department of Interior 1985c).

Acceleration of river basin development by the Corps of Engineers and the Bureau of Reclamation after the war threatened the integrity of various units of the National Park System. Strong opposition of conservation organizations and the National Park Service, generally but not always working together, largely stemmed these and similar threats to the integrity of the System and brought it through relatively unscathed (U.S. Department of Interior 1985c).

In 1964, the management of the Park System was organized into three park categories—natural areas, historical areas, and recreational areas—each with its own management concept and principles. Natural areas focused on preservation while maintaining compatible historic features. Historical areas reverse these emphases. In recreation areas, both historic and natural preservation were subordinated to management for outdoor recreation uses (U.S. Department of Interior 1985c).

Between 1945 and 1984, the number of National Park System units more than doubled and the area of the System tripled (table 19). Most of the increase came between 1978 and 1980 when over 47 million acres were added in Alaska. The System area in the contiguous 48 states totals 31 million acres. Wilderness areas have been designated by Congress within 39 units of the Park System. They total 38 million acres with 90% in Alaska (U.S. Department of Interior 1985b, 1985c).

The rapid growth of the Park System in recent years led to a general sense that it was expanding too fast. New park acquisitions slowed after 1980. Park visitors increased to 332 million in 1984, more than four times the level reported in 1960. The current focus of management is to emphasize improvement of stewardship rather than major new expansion. Restoration and improvement to stabilize and upgrade existing park resources and facilities is now the central policy. The separate management categories for natural, historic, and recreational areas were abolished in 1977. They have been replaced by a single set of management guidelines that cover the range of characteristics that occur in the park units. Parks are now zoned according to their various natural and cultural features. Zones are managed according to appropriate guidelines (U.S. Department of Interior 1985c).

Table 19.—Area and components of the National Park System.

Component	Federal area Units	Federal area Acres	Percent of total area
National parks	48	47,971,577	60
National preserves	12	21,106,350	26
National monuments	77	4,724,442	6
National recreation areas	17	3,687,006	5
National seashores	10	597,025	1
National rivers	4	359,993	a
National lakeshores	4	224,674	a
Wild scenic rivers	8	208,911	a
National parkways	4	163,226	a
Historical parks	26	150,790	a
Scenic trails	3	126,858	a
Subtotal	213	79,320,852	
Others	124	119,541	
Total	337	79,440,393	

[a] *Less than 0.5%.*
Source: U.S. Department of the Interior (1985b).

The Outdoor Recreation Resources Review Commission (ORRRC), authorized by Congress and appointed by President Eisenhower in 1958, was another important development for the nation's recreational interests. Its charge was "to determine the outdoor recreation wants and needs of the American people now and what they will be in the years 1976 and 2000; to determine the recreation resources of the Nation available to satisfy those needs...and to determine what policies and programs should be recommended to ensure that the needs of the present and future are adequately and efficiently met." The Commission published its findings and recommendations in 1962. The need for outdoor recreation opportunities was reported most urgent near metropolitan areas. Considerable land was available for outdoor recreation but it was not well located to meet the most urgent needs. The Commission made 52 highly specific recommendations. The most significant, perhaps, was to establish a national public land acquisition and recreational development program supported with federal and matching state funds. Congress responded with the enactment of the Land and Water Conservation Fund in 1964 through which 5.6 million acres of local, state, and federal park and recreation lands were acquired and developed in or near heavily populated urban centers. Other responses to ORRRC recommendations were the legislative establishment of natural systems of wilderness and wild, scenic, and recreational rivers and trails. In addition, more than 100,000 acres of surplus federal land was transferred to states and communities for park and recreation purposes. A Bureau of Outdoor Recreation was established in 1962 in the Department of the Interior but it has since been abolished (Davis 1983, Diamond et al. 1983).

State park development expanded rapidly after the war, responding to the boom in outdoor recreation and tourism that came in the 1950's. By 1970, the state parks numbered 3,425 with a total area of 8.6 million acres. They reported over 482 million visits in that year. Leadership of the state park movement during this period shifted from citizens and civic organizations to professionals. The National Conference of State Parks, formed in 1920, merged with the National Association of State Park Directors to form the National Recreation and Park Association. The management of state parks increasingly was placed in the hands of professionally trained park and recreation managers. The total professional staff serving state parks rose from 400 in 1950 to 3,400 in 1970.

In 1984, the area of state parks had expanded to more than 10 million acres and reported visitors were 666 million (Davis 1983, U.S. Department of Commerce 1987). The high level of visits to state parks and their relatively small acreage, compared to those for national forests and parks, emphasizes the local nature of a very large segment of recreation interests and demands as recognized in the ORRRC study in 1962.

Wildlife Management

State wildlife management programs thrived as the Pittman-Robertson (P-R) program expanded rapidly after World War II. In 1950, the P-R program was supplemented by the Dingell-Johnson Federal Aid in Fish Restoration Act giving states assistance for protection and management of sports fisheries similar to the P-R program. Obligated funds for both programs increased from less than $14 million in 1947, measured in constant 1982 dollars, to $57 million in 1965 and $95 million in 1984 (U.S. Department of Interior 1985a). States were enabled to purchase outright about 4 million acres of wildlife habitat. In 1984, state leases and cooperative agreements for wildlife management were in effect in 4,400 areas encompassing almost 40 million acres of public and private lands in all 54 states and territories. Practically all the acreage was available for hunting. Over 560,000 acres had been acquired and were being developed or managed as wildlife refuges. Populations of many birds and mammals of both game and nongame species have been restored, including the white-tailed deer, whose number has risen from less than a half million in 1920 to more than 14 million today. Nearly 4 million were harvested in 1980. Wild turkeys, which were scarce outside a few southern states in 1930, now number 2 to 3 million. Their harvest exceeded 250,000 in 1980; hunting seasons are permitted in 45 states. Elk numbered only about 100,000 in 1920, and now approach 500,000 with over 75% located on national forests. Similar accounts of population restoration can be cited for the gray and fox squirrels, Canada geese, antelope, beaver, black bear, desert bighorn sheep, mountain lions, bobcats, and many others (Trefethen 1975; U.S. Department of the Interior 1983, 1984a).

During the years 1980 to 1983, the total number of licensed hunters averaged a record 16.5 million. Total hunter days were almost 400 million in 1980. The upward trend in hunters, however, appears to be levelling with the influence of urbanization, higher education, rising population age, and the growing proportion of white-collar workers. Some organized opposition to hunting and game-oriented wildlife management emerged in the 1970's. This has fostered a growing management emphasis on protecting nongame species, including predators such as wolves, panthers, and coyotes (Fedkiw 1986a; Trefethen 1975; U.S. Department of Interior 1983, 1984a).

Federal refuges also expanded in this period. There are now 434 refuges in all states and territories except West Virginia. Excluding Alaska, their total area is 1 million acres. The 16 national refuges in Alaska total 17 million acres. In addition, there are 150 federal waterfowl management areas totalling 1.7 million acres and 58 wildlife coordination areas with 400 thousand acres.

The passage of the Endangered Species Preservation Act in 1966 and successive legislation has obligated the nation to protect all native animals and plant species whose survival is endangered through all or a major part of their range in the foreseeable future. The legislation established a distinction between endangered and threatened species. Threatened species are those likely to become endangered throughout all or a major part of their range in the foreseeable future. The Secretary of the Interior, who administers the act, identified 323 endangered species and 87 threatened species as of June 1986 (table 20). Federal agencies are obliged to manage their resources and programs in ways that do not jeopardize the listed species or destroy or adversely modify their critical habitat. The Department of Interior cooperates with states and the private sector to protect and manage ecosystems that endangered and threatened species depend upon. One hundred ninety-eight recovery plans have been developed for protecting 233 of the listed species on federal, other public, and private lands.

WATER RESOURCE PLANNING AND DEVELOPMENT AFTER 1945

Water resources development under federal programs accelerated rapidly in the 1940's and 1950's. The unprecedented authorizations of the 1944 Flood Control

Table 20.—Number of endangered and threatened species.

Species group	Endangered	Threatened
Animals	271	60
Mammals	45	4
Birds	76	5
Fish	43	25
Other[a]	56	26
Plants	103	27
Total	323	87

[a]*Snails, clams, crustaceans and insects.*

Act were a major force and influenced federal appropriations for water resource projects into the 1960's. The abolishment of the National Resources Planning Board in 1943 by Congress effectively undermined centralized executive branch oversight of water resources planning and development programs. Congressional attitudes increasingly favored ultimate decisionmaking on public works projects based on preferences of the congressional delegations of each district. Thus, projects sponsored by Members of Congress seldom received effective opposition except where there was serious local opposition. Each of the federal water resource agencies formed liaisons with its congressional committees and a separate approach based on its history, its jurisdiction, and the interests of the geographic clientele served by its programs. The Corps' emphasis focused on the needs of localities for structures that could deal adequately with catastrophic floods. The Bureau of Reclamation was motivated by its sense of the national importance of western regional economic development. The Soil Conservation Service favored maximum amounts of planned watershed protection from the viewpoint of agricultural soil and water protection for the nation (Burges 1979).

In 1954, Public Law 566 gave the Department of Agriculture authority to help local organizations plan and develop watershed improvement works for flood prevention and agriculture use, and conservation of water for watersheds smaller than 250,000 acres. This included Soil Conservation Service assistance with investigations and surveys, as well as the planning and evaluation of projects including structural works of improvement. This technical and financial assistance was furnished through PL 566 project agreements between the Soil Conservation Service and local organizations (Helms 1988, U.S. Department of Agriculture 1972).

Wise use and efficiency considerations continued to dominate water resource planning and development through the 1960's. Benefit/cost analysis and related principles and standards became important tools in justifying projects and assuring their efficient design. By the 1960's, however, the pace of water resource project construction was slowing as most of the big dams were completed. Many major river systems were heavily regulated or controlled—the Tennessee, Missouri, Colorado, Rio Grande, Ohio, Columbia, Arkansas, Red, Mississippi, and those in California's Central Valley. There were few large river systems remaining for major work. Most of the efficient opportunities for water resource improvement works, including small watersheds, had been identified and completed or were under construction. Pressure for retrenchment of federal investment increased during the 1960's. Increasing emphasis was placed on state water resource planning and greater state and local financing (U.S. Department of Agriculture 1972, Willeke 1979).

Toward the end of the 1960's it became evident that despite the development of major flood control works, property damage and loss from flooding were persistently rising on the flood plains. Although flood protection measures were effective in controlling floods, they were also inducing expanded investments and development on the better protected flood plains. Federal policy emphasis thus shifted toward nonstructural measures, such as more effective use of flood insurance, restriction of intensive development, and greater use of the flood plains for recreation and aesthetic purposes and other less intensive uses.

Water Quality

Water quality and related amenity interests in water resource development received increasing attention after World War II, but largely in ad hoc terms until the 1970's. Recreation, for example, was authorized as an appropriate multipurpose objective in the 1944 Flood Control Act. In 1954, the Fish and Wildlife Coordination Act provided for systematic assessments of the expected effects of federal water resource projects on fish and wildlife. The assessments were prepared by federal and state fish and wildlife experts and often led to the addition of mitigation measures, such as fish screens, ladders, and hatcheries or the use of reservoir storage capacity for conservation objectives (U.S. Department of Agriculture 1972). Recreation developments around reservoir areas expanded rapidly in the 1960's in response to booming outdoor recreation demands. Beginning in the 1960's, channelization of upstream watershed habitats was seen as harmful to fish and wildlife aquatic habitats and was strongly restricted in federal programs. The drainage of wetlands was likewise seen as having similar adverse effects and also restricted in federal programs.

Systematic planning for water quality and related amenity and environmental considerations began following the passage of the National Environmental Policy Act of 1969 (NEPA). The Act addressed a multiplicity of environmental concerns relating to all resources and stated general national goals and policies. In particular, it required the preparation of environmental impact statements describing the effect of significant proposed actions and decisions, and alternatives to those actions, on environmental conditions. Both a draft statement subject to public review and comment and a final statement reflecting response to public review comments were required. In this way, environmental quality analysis and planning became a part of federal water resources planning and development along with economic efficiency and engineering effectiveness in the early 1970's. The NEPA process similarly affected planning and development for all other resources in federal programs (Ortolano 1979).

In 1972, the Clean Waters Act made "fishable and swimmable" water a national goal for the nation's surface waters. By the late 1980's, substantial progress had been made in reducing discharges of pollutants such as organic matter, sediment, nutrients, salts, and bacteria from point sources such as industrial plants and municipal wastewater treatment facilities. Nonpoint sources of pollution such as urban runoff or sediment from erosion of agricultural lands were seen as the major causes of degradation where water quality was still a problem. In such locations in 1986, nonpoint sources were

impairing use in 75% of the lake acres, 65% of the stream miles, and 45% of the estuaries (Hanmer 1988).

In 1986, the EPA National Water Quality Inventory estimated that about 75% of the nation's surface waters that were assessed were clean enough for fishing and swimming (U.S. Environmental Protection Agency 1987). When the more distant lakes and upper reaches of streams which were not assessed and largely free of pollutants are included in the base, this percentage would probably be closer to 90%.[16]

A joint National Fisheries Survey conducted by the U.S. Fish and Wildlife Service and the Environmental Protection Agency in 1982 found that sport fish, such as rainbow trout and largemouth bass, are found in 73% of the Nation's inland waters and that 67% of streams are suitable as sport fish habitat (Council of Environmental Quality 1985). The preliminary results of the 1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation show a substantial increase in the number of number of people fishing and fishing days of participation since 1980 (U.S. Department of Interior 1987). The number of people who fish increased almost 11%, more than double the population growth rate. Total days of fishing increased over 15%. The number of days per person fishing and average length of trips also increased. Total outdoor recreation growth was about the same as population growth (Domestic Policy Council 1988). Thus, the relative increase in fishing demand since 1980 can be seen as an apparent response to the improving quality of surface waters. The increase in total days of fishing was greatest for inland waters, 17%, compared to 7% for saltwater fishing.

OUR TRANSFORMED HERITAGE

Today, the nation's transformed heritage of forests, grassland, and croplands covers 1.63 billion acres compared to 1.75 billion acres in 1880 and probably somewhat more in the presettlement period (table 1). This excludes 362 million acres in Alaska which is still largely undeveloped rangeland and forest. It also excludes Hawaii and various territories.

Other land uses total 266 million acres. They include the places where most Americans live and work, their travel ways, and their parks and wildlife refuges. When account is taken of the lawns, gardens, trees, and shrubs in these areas and their aesthetic qualities, they represent an important part of our transformed heritage. Their value often exceeds the highest values placed on the nation's more remote and extensive forests, grasslands, and croplands.

Another contrast is in the numbers of Americans supported by these resources. They have grown by 120 times to 240 million. In addition, exports provide equivalent support for 100 million or more people in other lands. Yet, the capacity to produce more remains large, and the potential of technology to expand that capacity is also seen as large. Resource protection, improved management, technology, wise use, and time have revealed the resilience of our natural resources, in many ways unexpected in the 19th and early 20th centuries. They have also confirmed their renewability. Mineral resources, since they are not renewable, have been reduced. There are weaknesses in the domestic supply of some important minerals relative to demands. Our dependence on new technology and imports has increased.

Time has also tested our policies and programs and our resource managers, both public and private. They appear to have served Americans well. Time has likewise taught us that it may require decades, rather than years, to bring about the resource productivity and conditions that best serve the nation's needs. Resource assessment, planning, and foresight are important determinants for assuring resource abundance.

EPILOGUE

Most renewable resources and their outputs appear to be sufficiently abundant to meet the needs of the nation with prudent management and the promise of emerging and new technology. Generally the quality of these resources and their outputs is improving. To the limited extent that forecasts can be made with any degree of reliability, the foreseeable future should see continued relative abundance and improving resource quality and outputs. This applies to crops, livestock, and timber as well as to the croplands, grassland, and forests. It also applies to wildlife, parks, wilderness, and related recreation and aesthetic opportunities. Certainly the claim can be made that a great deal of progress has been achieved in resource production, productivity, and conditions during the past several decades.

Nevertheless, there are continuing issues and problems relating to resource production, productivity, conditions, and use on public and private lands. They are the subject of considerable debate among diverse individuals and organizations. As this debate goes on in our democratic environment, resource management and use continue to respond to the objectives of resource owners and managers, the market place, and the requirements of our laws and regulatory institutions.

National economic conditions limit how fast or effectively national needs can be addressed, and they impact the management and use of renewable resources and minerals. So, a major challenge is how to assess resource issues in the context of total national concerns, and how to relate them to each other in some sense of priority.

In the face of visible improvement, relative abundance, favorable programs, and trends, the resource management debate seems to be related more to: (1) the balance of resource uses and the distribution of their benefits to different segments of our society; (2) the rates of improvement among the resources uses and conditions; (3) the local and specific exceptions to the general trend; and (4) the general impact of these matters on the future welfare of the nation. Factors conditioning the debate include:

[16] *Telephone conversation with Rob Wolcott, U.S. Environmental Protection Agency, Washington, DC, September 21, 1988.*

- The current multiplicity of single resource interests;
- Philosophical differences over the value of uses ranging from pristine, natural conditions to intensive use and management;
- Lack of adequate and reliable data on the actual dimensions of some resource issues and problems;
- The relative roles of the federal, state, and local governments and the private sector;
- Efforts to reduce public spending that emphasize the question of who should pay for the cost of improving resource productivity and conditions;
- Expanded use of the democratic opportunity to make a case before federal, state, and local legislative, executive, and judicial representatives; and
- Recognition of the limited ability of the marketplace to respond to issues of value and preference of all resource interests.

Past debates and action have often altered the use and management of renewable resources as public and private landowners have responded to the marketplace. Public consensus continues to be difficult to achieve with the growing fragmentation of resource interests. Nevertheless, some debate is healthy and contributes to the laws, programs, and regulations that help to bring about favorable resource conditions and trends.

Much of the nation's resource improvement resulted from problems—which began as private, local, or state problems—that fell into the hands of the federal government when the Great Depression disabled the capabilities of states and the private sector to deal with them. Now, as renewable resources are on an upward path, a more appropriate balance may properly return stronger control to the states, local governments, and the private sector to deal with them.

Past performance clearly indicates that our resources are both resilient and renewable. This is true for soils, forests, grassland, wildlife, fish, and both air and water quality. The most important historical lesson, however, is the need for continuous vigilance. With the enormous and growing pressures of population and economic growth, and the intensifying public use of renewable resources for most all purposes, the strongest assurance for continuing improvement lies in the periodic measurement and open, public assessment of resource productivity and conditions for meeting ongoing and future needs of the nation. Measurement must be sufficiently intensive to establish "baseline data" for monitoring the renewable resources and be useful for national, state, and substate assessments.

Adverse resource conditions and trends, when they arise, are usually localized and contained within state borders. Their identification at those levels helps to assure they do not become larger problems. That is the task of measurement and assessment—to identify emerging resources issues and problems and credibly quantify their actual dimensions and distribution. This is a primary role—"vigilant stewardship"—for federal and state resource agencies, together with delivery of resource information to the nation's policy leaders, the general public and experts alike. When serious problems are found, policy questions and options need to be raised, evaluated, and debated in terms of what, if anything, should be done, by whom, and for whom.

With the foregoing in mind, the lead role for resource measurement and assessment lies largely with the federal government, mainly because that is the only way complete, standardized, and geographically consistent information can be acquired at a reasonable cost. However, there is a substantial role for state and local governments and the private sector in gathering needed data. This is exemplified by the important state and local government and private participation in the forest survey and the national resource inventory conducted by the U.S. Department of Agriculture's Forest Service and Soil Conservation Service, respectively.

State capabilities in resource assessment and management have increased substantially in recent years, along with their managerial and financial capability to respond to critical problems. These capabilities will grow in response to perceived or emerging resource needs, if periodic resource data and assessment information are made available to the public and its leadership. Land use and related resource planning is widely recognized as a state role and often seen as constitutionally reserved to the states. The growth of state interests and capabilities in resource assessment and planning reflects the growing understanding of state leaders and their citizens that knowledge of resource conditions and trends are important for assuring their economic, social, and environmental welfare.

A number of continuing resource issues will require the attention of policy leaders, resource managers, and the public now and in the future. These include:

- Adjusting public and private agricultural production management and expansion of export markets to improve the economic welfare of the farming and ranching industries;
- Conserving agriculture lands that are vulnerable to serious soil erosion and other forms of resource degradation;
- Developing a more rational basis for allocating lands to wilderness use in relation to other resource needs and determining how much of the current 30 to 40 million acres of federal land presently under review warrants conversion and addition to the designated 88 million acres of the National Wilderness Preservation System.[17]
- Determining how to meet the outdoor recreational needs of a population increasing in size and affluence, working out the appropriate federal, state, and local government and private roles, and establishing policies for financing increased facilities, services, and maintenance that are equitable to users and taxpayers alike (Diamond et al. 1983, Fedkiw 1986c, Schaub 1983).

[17] *Data on designated wilderness areas and additional areas under review provided by Forest Service, Division of Recreation Management.*

- Preventing or avoiding adverse effects of pollution on surface and groundwaters, particularly from the use of pesticides and fertilizers (Association of State and Interstate Water Pollution Control Administrators 1985, Environmental Protection Agency 1984, Gianessi et al. 1986, Holden 1986, National Research Council 1986, Schaub 1983, U.S. Geological Survey 1985);
- Managing harvests and road development on national forests in a way that balances wilderness, recreational, wildlife, and timber needs of the nation;
- Managing the use of the increasingly valuable surface and groundwater supplies, particularly in the arid sections of the West (Englebert and Schewring 1984, High Plains Associates 1982);
- Assuring an adequate supply of minerals and energy sources.

Other continuing issues relating to resource management include the loss of wetlands, sodbusting on highly erodible soils, salinization, desertification, and control of predators on domestic stock. These are largely site-specific issues or problems, with more or less uncertain dimensions, but they have received some national attention. Additional issues, such as threatened and endangered species, recovery of wildlife populations, the management of nonindustrial private lands, and range conditions have been more prominent and received more attention. One resource issue has abated as a result of improved measurement and assessment and dropped from the national agenda. That was the concern for an apparent accelerated and unacceptable rate of loss of farmlands in the 1970's (Easterbrook 1986). However, it may remain an issue in some states and at local levels.

Some resource problems originate largely in urbanized and industrial areas. They include acid rain, ozone and other photochemical oxidants, the rising concentration of carbon dioxide and other atmospheric chemicals, and solid and toxic wastes that are disposed of on the land. These problems potentially threaten the production and use of renewable resources to a far greater degree than those associated more directly with resource use and management.

The foregoing issues are indicative of our vigilance and concern for croplands, grassland, and forests and their production and services. Most are the subject of some degree of research, systematic measurement, and assessment, as well as a great deal of debate and rhetoric. These characteristic ways in which we address issues reflect our national education and scientific orientation. They also reflect the political dimensions of our society. Although these processes can benefit from better public education and information about our land and renewable resources, there is a clear consensus for vigilance over the nation's resources. There is less consensus about how, by whom, and to what extent each of the issues should be addressed and who should bear the cost burden. But, we should be thankful for the vigilance. Landowners and managers, meanwhile, will continue to manage both public and private land and await the outcome of the debate, influencing it where they can.

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- Preventing or avoiding adverse effects of pollution on surface and groundwaters, particularly from the use of pesticides and fertilizers (Association of State and Interstate Water Pollution Control Administrators 1985, Environmental Protection Agency 1984, Gianessi et al. 1986, Holden 1986, National Research Council 1986, Schaub 1983, U.S. Geological Survey 1985);
- Managing harvests and road development on national forests in a way that balances wilderness, recreational, wildlife, and timber needs of the nation;
- Managing the use of the increasingly valuable surface and groundwater supplies, particularly in the arid sections of the West (Englebert and Schewring 1984, High Plains Associates 1982);
- Assuring an adequate supply of minerals and energy sources.

Other continuing issues relating to resource management include the loss of wetlands, sodbusting on highly erodible soils, salinization, desertification, and control of predators on domestic stock. These are largely site-specific issues or problems, with more or less uncertain dimensions, but they have received some national attention. Additional issues, such as threatened and endangered species, recovery of wildlife populations, the management of nonindustrial private lands, and range conditions have been more prominent and received more attention. One resource issue has abated as a result of improved measurement and assessment and dropped from the national agenda. That was the concern for an apparent accelerated and unacceptable rate of loss of farmlands in the 1970's (Easterbrook 1986). However, it may remain an issue in some states and at local levels.

Some resource problems originate largely in urbanized and industrial areas. They include acid rain, ozone and other photochemical oxidants, the rising concentration of carbon dioxide and other atmospheric chemicals, and solid and toxic wastes that are disposed of on the land. These problems potentially threaten the production and use of renewable resources to a far greater degree than those associated more directly with resource use and management.

The foregoing issues are indicative of our vigilance and concern for croplands, grassland, and forests and their production and services. Most are the subject of some degree of research, systematic measurement, and assessment, as well as a great deal of debate and rhetoric. These characteristic ways in which we address issues reflect our national education and scientific orientation. They also reflect the political dimensions of our society. Although these processes can benefit from better public education and information about our land and renewable resources, there is a clear consensus for vigilance over the nation's resources. There is less consensus about how, by whom, and to what extent each of the issues should be addressed and who should bear the cost burden. But, we should be thankful for the vigilance. Landowners and managers, meanwhile, will continue to manage both public and private land and await the outcome of the debate, influencing it where they can.

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins
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**General Technical
Report RM-176**

A Description of Forest Service Programs and Responsibilities

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Section 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Fores. Service analysts prepared a number af assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

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A Description of Forest Service Programs and Responsibilities

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A Description of Forest Service Programs and Responsibilities

INTRODUCTION

This study describes the programs and responsibilities of the Forest Service, as called for in Section 3(a)(3) of the Forest and Rangeland Renewable Resources Planning Act of 1974 as amended.[1] This Act directed the Secretary of Agriculture to prepare each tenth year after 1979 an updated Renewable Resource Assessment which would include:

"A description of Forest Service programs and responsibilities in research, cooperative programs, and management of the National Forest System, their interrelationships, and the relationship of these programs and responsibilities to public and private activities."

This study is in response to that legislative direction. It is a part of the 1989 RPA Assessment of the Forest and Range Land Situation in the United States. The research, cooperative assistance, and land management programs conducted by the Forest Service affect almost all forest lands in the United States including timberlands, woodlands, brushlands, grasslands, and alpine areas; rangelands; and the associated waters. These lands and associated water areas total some 1.6 billion acres, or about 70% of the total area of the United States.

About 483 million acres of this area is classified as timberland, i.e., suitable and available for production of timber crops. These lands are generally managed or held for uses such as recreation, wildlife, grazing, water production, and watershed protection. Nearly three-fourths of this area is privately owned in several million private ownerships, with the remaining one-fourth in federal, state, or local public ownerships. The other forest and rangelands are primarily valuable as watersheds and for recreation, wildlife habitat, grazing of livestock, mining, or other nontimber uses.

Forest Service activities are also concerned with the management of trees, forests, and associated resources in and near urban areas. In addition, forest research and cooperative programs include substantial efforts to develop and apply new technology in products utilization and to provide help to thousands of operators and loggers in wood-using industries and to millions of consumers who use forest products for housing and other purposes.

The programs conducted by the Forest Service represent the major effort to protect and manage the Nation's forest resources, and a significant part of federal action to protect and manage rangelands and water resources. Providing national leadership in forest conservation policies and programs is also a basic function of the Forest Service, as directed in the National Forest Management Act of 1976:[2]

> The Forest Service...has both a responsibility and opportunity to be a leader in assuring that the Nation maintains a natural resource conservation posture that will meet the requirement of our people in perpetuity.

In carrying out its responsibilities, the Forest Service engages in a wide diversity of activities that have been grouped into four major programs:

1. Comprehensive research programs aimed at the solution of problems relating to the management of all types and ownerships of forests, rangelands, and associated waters; and to the industrial, environmental, and other uses of these natural resources.

2. Nationwide cooperative forestry programs conducted with state forestry agencies in efforts to protect and improve nearly a billion acres of forests, rangelands, and associated water resources in private and nonfederal public ownerships.

3. Direct administration of 191 million acres of national forests, national grasslands, and Land Utilization Projects, and the management of their resources for the use of people.

4. Participating in programs aimed at developing employment and training opportunities for disadvantaged people and the support of human and community values.

The relative size of the major Forest Service programs, as indicated by the availability of supporting funds in fiscal year 1988, is as follows:

Program	Supporting funds (thousand dollars)
Forest research	138,418
Cooperative rorestry	89,699
National Forest System	1,960,204
Human resource programs	82,400
Total	2,270,721

These figures include both direct appropriations to the Forest Service and transfers of funds from other public agencies and private sources. Some funds appropriated to the Forest Service, particularly for State and Private Forestry activities, are allocated to states and other cooperators for locally administered programs.

Other agencies also manage federally owned forest and range resources, provide assistance to state and private owners of forests and rangelands, or conduct research on forest and range problems. Federal environmental protection programs also affect all resource management agencies and resource uses. Similarly, state agencies play an important role in forest land management, in forest and range research, and in environmental protection programs on private forests and rangelands. Many industrial and conservation organizations conduct programs that influence the use of the Nation's forests and related resources.

The development of cooperative relationships between the Forest Service and other federal and state resource agencies and private organizations is of major importance in developing and carrying out forest and range conservation programs. In both the formulation of forestry policies and in the management of forest and associated resources, the Forest Service works in partnership with many agencies and organizations, and with continuing involvement of the concerned people. The text that follows describes such interrelationships between the Forest Service and other organizations, and those activities for which the Forest Service has direct responsibility.

Most of the following material has been taken from "A Description of Forest Service Programs and Responsibilities" in "An Assessment of the Forest and Range Land Situation in the United States," 1981;[3] "The Principal Laws Relating to Forest Service Activities";[4] "Report of the Chief of the Forest Service, Fiscal Year 1987";[5] and the 1989 Budget Explanatory Notes for Committee on Appropriations."[6] The material was prepared in collaboration with the American Forestry Association.

Additional details on Forest Service programs, administrative regulations, and other pertinent data may be found in Federal laws concerning the Forest Service and its activities, in the Code of Federal Regulations, the Forest Service Manual and Handbooks, and in other material referred to in the following text.

FOREST SERVICE RESEARCH PROGRAMS

The purpose of Forest Service research is twofold; first, to develop new scientific knowledge and technologies that will enhance the management, productivity and use of forests, rangelands and the associated waters; second, to utilize the products and services in ways that increase the economic, social and environmental benefits from these resources.

The definition of "forestry and range" research is somewhat arbitrary, however. Private research dealing with basic problems of equipment development or markets often contributes in important ways to the solution of forestry and range problems. Resource surveys and collection of useful statistical data are usually classified in research programs, whereas limited surveys and planning for specific project work are usually part of project operations or action programs. Some activities involve inseparable mixtures of research, development, education, and demonstration work.

Most of the forest and rangeland research in the United States is publicly supported, with Forest Service research accounting for roughly two-thirds of the public funding. The public responsibility for forestry and range research largely reflects factors such as:

- the large number and small size of most private forest and rangeland ownerships and operations and the consequent inability to organize and finance effective research programs.

- the broad societal nature of benefits obtainable from increased productivity of forests and rangelands and the associated waters, and the increased supplies of timber and other goods and services.

- the lack of conventional markets and market prices for research results.

- the need for information and improved technology by public resource agencies that manage large areas of public lands and administer public assistance programs to promote improved resource management on private lands.

- the need for information by many sectors of the public concerned with management and utilization of forests and other natural resources.

Authorization for Forest Service Research

Public research in forestry began in 1876 with the establishment of a Division of Forestry in the U.S. Department of Agriculture. This new agency was charged with

conducting a broad investigation of the Nation's forest resources as a basis for evaluating forestry problems and identifying needed policies and conservation programs.

With the creation of the Forest Service in 1905 in the Department of Agriculture, forestry research received new emphasis under the Department's general charter, along with the strengthening of protection and management of the newly designated national forests. A regional forest experiment station was set up in 1908 in the Southwest, and pioneering studies were undertaken on experimental forests, ranges, and watersheds. Other experiment stations were established later in other regions. The Forest Products Laboratory was set up in 1910 in cooperation with the University of Wisconsin. In 1915, a branch of research was organized in the Forest Service to plan and direct an expanding program of studies both on National Forests and on other lands. The Clarke-McNary Act of 1924[7] included specific authorization for studies of problems of forest taxation and insurance of standing timber.

With the passage of the McSweeney-McNary Act of 1928[8] the Forest Service was:

> Authorized and directed to conduct a comprehensive program of investigations to determine, demonstrate, and promulgate the best methods of reforestation and of growing, managing, and utilizing timber, forage, and other forest products, of maintaining favorable conditions of water flow and the prevention of erosion, of protecting timber and other forest growth from fire, insects, disease, or other harmful agencies, of obtaining the fullest and most effective use of forest lands, and to determine and promulgate the economic considerations which should underlie the establishment of sound policies for the management of forest lands and the utilization of forest products....

Authorization was included for a system of regional forest experiment stations, for cooperation with public and private agencies in the United States and abroad, and for receipt of cooperative contributions. The broad scope of investigations that has evolved under this basic charter and related legislation is indicated in these descriptions of current Forest Service research activities.

Further congressional direction of Forest Service research was incorporated in the Forest and Rangeland Renewable Resources Planning Act of 1974, which provided for periodic assessments of all the renewable resources on America's forests and rangelands, together with development of program alternatives for the conservation and development of these resources. The required analyses included present and prospective demands for the products and services obtainable from forests and rangelands, present and prospective resource supplies, and opportunities for improving yields of the goods and services obtainable from these lands through resource management and development programs. This work is closely coordinated with related assessments of soil, water and related resources of the nation, conducted by the Soil Conservation Service.

The National Forest Management Act of 1976[2] contained further direction for studies relating to forest and range resources by including provisions for reports on opportunities for increasing use of fiber and wood wastes on National Forest lands.

In 1978, the Forest and Rangeland Renewable Resources Research Act[9] replaced the McSweeney-McNary Act of 1928 with a broader charter for research on forest and range renewable resources in rural, suburban, and urban areas. The Act also incorporated related legislation applying to research grants and funding, provided guidance for the conduct of research programs, removed limitations on research appropriations, and authorized cooperative research in other countries.

Scope and Goals of Forest Service Research

This legislation directs the Forest Service to conduct, support, and cooperate in investigations, experiments, tests, and other activities necessary to obtain, analyze, develop, demonstrate, and disseminate scientific information about establishing, protecting, managing, and utilizing forest and range land resources in rural, suburban, and urban areas. Research must include, but not be limited to:

1. Protection research related to protecting vegetation and other forest and range land resources, threatened and endangered flora and fauna and wood products from fires, insects, diseases, noxious plants, animals, and air pollutants. It also includes research related to protecting people, natural resources, and property from fires in rural areas.
2. Analysis and assessment research related to development and application of scientific knowledge required to make and keep current a comprehensive survey and analysis of the present and prospective requirements for renewable resources of forests and range lands and the supplies of such renewable resources. The research must also include a determination of present and potential land productivity, and such other facts as may be useful in determining methods needed to balance the supply and demand of these renewable resources as well as their benefits and uses for the people of the United States.

3. Management research related to managing, reproducing, planting, and growing vegetation on forests and rangelands for timber, forage, water, fish and wildlife, esthetics, recreation, wilderness and energy production, and conservation.

4. Environmental research related to understanding and managing surface and subsurface water flow, prevention and control of erosion, and the restoration of damaged or disturbed soils on forest and range land watersheds. It also includes research related to maintenance and improvement of wildlife and fish habitats; management of vegetation to reduce air and water pollution; and the understanding, prediction and modification of weather, climate and other environmental conditions which affect the protection and management of forest and range lands.

5. Utilization research related to harvesting, transporting, processing, marketing, distributing, and utilizing wood and other materials derived from forest and rangeland renewable resources. It also includes research related to the recycling and utilization of wood fiber, the production and conservation of energy, and the testing of forest products.

Program Areas

Research in the Forest Service has been classified into several program areas for budgetary and administrative purposes. It has been increasingly recognized, however, that many research problems and projects transcend the boundaries of any particular subject areas, and that solutions of most problems require coordinated study by a variety of scientists and disciplines. Thus, some of the work in each of the program areas described below have relevance in solving problems in other areas of research.

The funds for each major Forest Service Research program are shown in table 1 for fiscal year 1988.

Forest Protection Research

The largest appropriation was for the forest protection program; research designed to increase the productivity and health of forest and range resources through improved knowledge of fires, atmospheric factors, and insect and disease pests. The program is divided into two parts: Forest fires and atmospheric science, and forest insect and disease.

Table 1.—Forest Service funds for forest research programs, by fiscal year 1988.

Program	Funds *(thousand dollars)*
Forest protection research:	
Forest fires and atmospheric science	8,945
Forest insect and disease	22,545
Subtotal	31,490
Resource analysis research:	
Forest inventory and analysis	17,664
Renewable resources and economics	4,977
Forest recreation	2,712
Subtotal	25,353
Timber management research	26,548
Forest environment research:	
Watershed management and rehabilitation	16,692
Wildlife, range and fish habitat	12,567
Subtotal	29,259
Forest products and harvesting research	19,860
Total forest research appropriations	132,510
Competitive grants	3,000
Research construction	2,908
Grand total	138,418

Forest fires and atmospheric science.—The basic objectives of the forest fires and atmospheric science research program are: to develop improved knowledge of the initiation, behavior, and effects of fire on forest and range environments; to apply that knowledge by developing better methods of preventing and controlling wildfires, and using prescribed fires for enhanced forest resource protection and production; and to better understand atmospheric factors affecting forest productivity and health as well as biosphere/atmosphere relationships. Research also aims at developing fire-behavior prediction systems, fire safety and prevention guidelines, and fire-suppression tools for use in adjoining wildland/urban areas.

Current research includes efforts to:

- increase basic knowledge regarding the physics and chemistry of forest and range fuel, combustion, as well as the behavior of fire under different environmental conditions.
- develop methods to reduce and prevent forest and range fires, (both lightning and human-caused) by new and improved technology, including such measures as cloud-seeding.
- devise practical methods to reduce fire hazards by measures such as prescribed burning or timber salvage.
- improve methods for forest fire control to reduce fire suppression costs and losses of resources on

both forests and range lands, including more efficient planning for fires, fire attack, and improvement of fire control equipment.

- develop procedures for situating weather stations to most effectively diagnose threatening fire or weather conditions.

- develop systems to predict the atmospheric capacity to disperse forest fire smoke and to select the best times for using prescribed fires, i.e., times when smoke particles will rapidly disperse.

- develop standards for characterizing and measuring the effects of pollutants such as sulfur and photochemicals deposited from the atmosphere on wild and planted forest lands, and for monitoring how land and water resources affected by these pollutants change over time.

Forest insect and disease research.—The forest insect and disease research program is directed at developing technology that prevents or reduces forest and rangeland damage by insect and disease pests and that protects wood in use and storage from insects and decay. It is also directed at developing environmentally safe and effective strategies for pest management and integrating pest management with forest resource management.

Current research includes efforts to:

- increase basic understanding of the physiology and nutritional requirements of insects and plant disease.; and the role of biological and environmental factors influencing outbreaks of destructive forest insects and infectious pathogens such as fungi, bacteria, viruses, nematodes, and mistletoe.

- develop specific microbial, parasitic, or other biological agents for control of the Douglas-fir tussock moth, the gypsy moth, and similar major pests.

- develop ways for rapidly testing and propagating trees naturally resistant to disease.

- develop survey techniques and methods for evaluating and predicting biological and economic impacts of destructive insects and diseases on forest resources and on wood products in storage and use.

- develop means of identifying organisms such as fungi, bacteria, insects, and other organisms that cause deterioration of forests and forest products.

- identify safer chemicals for suppressing pest populations such as systemic fungicides, insect attractants, repellents, or other behavioral chemicals and nonpersistent toxicants.

- develop specialized equipment and improved techniques for safe and efficient application of pesticidal materials to trees and other cover on forest and rangelands and to wood products in processing, storage, or consumer uses.

- develop integrated control systems for minimizing losses to insects and diseases or other pests through combinations of decision support systems, silvicultural practices, and biological or improved chemical control methods.

Resource Analysis Research

The Forest Service resource analysis research is designed to provide comprehensive, continuing inventory information on the forest land resources of the United States; to determine the effects of economic and institutional forces on domestic and international forest products markets and forest management strategies; and to develop improved methods for managing outdoor recreation and wilderness resources, including forests in and near urban areas.

In a broad sense this research provides a scientific basis for assessing the current condition and outlook for forest land resources, forest product investments and markets, and outdoor recreation opportunities. It also provides methods for improving recreation services. The three major components of this research are summarized as follows:

Forest inventory and analysis.—The purpose of this research program is to provide comprehensive and continuing information on the extent, location, ownership, condition, and productivity of timberlands and timber inventories together with information on timber product markets; past and prospective trends in forest and rangeland resources are investigated, as well as opportunities to increase and extend supplies of renewable resources.

Current research includes:

- periodic surveys of the forest resources of each state. The 1987 surveys were carried out on 45 million acres.

- analyses of past and prospective changes in timber resources in the South and of all resources in all forest and rangeland regions of the country.

- work to develop improved and lower cost ways of inventorying and analyzing changes in renewable resources.

- analyses of economic opportunities to increase timber supplies.

Renewable resources and economics.—This research program is primarily concerned with analyzing the responses of domestic and international forest product markets to economic and institutional forces and structuring economically efficient forest management programs for both public and private forests.

Current research includes work to:

- evaluate the economic and social costs and benefits of alternative methods of timber growing, harvesting, processing, marketing, and product distribution to improve efficiency of operations and enhance benefits from use of available resources.

- provide economic and social guidelines for multiple-use management of forests and rangelands for production of water, recreation, livestock, fish and wildlife, esthetics, and timber.

- analyze alternate government policies and programs for improving management of forests, rangelands, and related resources and to evaluate the economic and social costs and benefits and the responses of private landowners, industry, and the public.

- provide economic information on markets for forest products in western Europe and the Pacific Rim countries.

- determine the costs and benefits of forestry research.

Forest recreation.—The forest recreation research program is concerned with developing technology to manage wildland resources, including those in and near urban areas, and to supply more and higher quality outdoor recreation opportunities.

Recreation research now underway includes studies to:

- increase understanding of interactions between people and wildland resources and to evaluate social, economic, or other factors which affect use and enjoyment of wilderness and other recreation resources.

- develop practical methods to maintain, restore or improve developed recreation sites, including those on fragile ecosystems.

- determine ways of designing and developing small natural areas to achieve the perception of spaciousness desired by visitors.

Timber Management Research

The timber management research programs seek to improve silvicultural alternatives, to develop guidelines for increased productivity and multiple-use benefits from forest lands, to maximize the growth and quality of trees, and to maintain land productivity. The research includes work to:

- develop or improve methods for the establishment, culture, and harvesting of timber and related crops for commodity uses.

- apply genetics and advanced biotechnology to forestry problems. Topics investigated include: determination of genetic variation in forest trees; seed selection; and the development of strains or hybrids characterized by superior growth rates, wood quality, resistance to insects diseases or other damaging factors, or of special value for environmental improvement in urban areas.

- develop techniques of timber measurement and for determining growth and yields of forests, including the influence of site, culture, or other factors on timber production and quality.

- determine the effects of herbicides used to control unwanted vegetation on ground water supplies.

- improve methods of tree establishment and culture in shelterbelts for soil and water conservation, and in urban and suburban areas for esthetic and other environmental purposes.

- develop more cost efficient site preparation and forest management practices, principally for the benefit of smaller, nonindustrial forest owners.

Forest Environment Research

Forest environment research provides knowledge and technology for management and enhancement of forest and range nontimber resource values. Of particular attention are wildlife and fish habitats, water quality and quantity, and forage.

Wildlife, range, and fish habitat research.—This research aims at developing knowledge and technology

for maintaining or improving wildlife and fish habitat; for improving soil stability, vegetative cover, and the condition of rangeland; and for integrating wildlife, fish, and livestock with other forest and rangeland uses.

Current research includes work to:

- devise methods for maintaining or improving the natural habitat for wildlife and fish through such measures as prescribed burning, planting for wildlife food or cover, fertilizing, stream shading, or modification in timber and range management practices to increase production and diversity of big game, song birds, fish, and other wildlife.
- develop resource management methods to assure maintenance of required habitat for endangered or threatened species of animals and plants.
- apply knowledge of genetics to improve browse and other forage plants in order to enhance carrying capacity for both livestock and wildlife.
- increase basic knowledge of ecological, physiological, and nutritional requirements of forest wildlife and fish populations and habitat.
- improve systems of range management on forest-related rangelands in both western and southern areas, with the aim of increasing forage and livestock production while protecting other uses and environmental values.
- improve methods for evaluating trends in range conditions and livestock production potential, and the costs and benefits of range management and capital improvement.
- develop effective methods for range improvement, including such practices as the conversion of brush or low-value trees to grass cover; reseeding of improved species of forage; control of undesirable plants by fire, chemicals, or other means; and revegetation of devastated areas.

Other nontimber resource research.—The water related research aims to develop and test new cost-effective methods for rehabilitating lands disturbed by surface mining and to protect, manage and improve forest and rangeland watersheds.

Current research includes studies to:

- increase basic knowledge of forest soil characteristics, erosion hazards, nutrient cycles, and vegetation-water relationships on forests and rangelands.
- determine the responsiveness of lakes to atmospheric deposition.
- determine the effects on soils and water flows of various land use and management practices such as logging, grazing, and forest fertilization.
- develop methods for managing forests and rangelands to stabilize soils; limiting erosion and sedimentation; improving yields, timing, and quality of water flows; and rehabilitating degraded landscapes.
- develop techniques for reducing water losses from plants, soils, snow, and water surfaces to enhance usable supplies of water.
- develop ways to restore and stabilize forest lands disturbed by strip mining and to reduce acidity, sedimentation and flooding in affected streams.
- evaluate the effects of coal and other mineral mining on forests and rangelands; on forest uses; on associated communities; and on environmental values.
- develop effective methods to minimize adverse effects of surface mining on resources and environmental values.
- test and demonstrate alternative methods for the planning of mining operations and for the rehabilitation of mined areas in cooperation with other U.S. Department of Agriculture agencies, Department of Interior agencies, states, and other groups.

Forest Products and Harvesting Research

Products and harvesting research aims to provide technology to harvest and use timber more efficiently. Topics being investigated include: development of timber harvest and transport systems which are at once economically efficient and environmentally acceptable; improvement of wood product performance in use; expansion of wood product export; reduction of waste, costs, and energy consumption in wood processing; and facilitation of forest management and environmental protection through improved harvesting and use of wood.

Current research includes efforts to:

- determine the fundamental characteristics as well as the mechanical, physical, and chemical properties of the many tree species which have present or potential importance for commercial uses.

- develop new or more efficient processes for wood product manufacture, and for such wood-based products as pulp, paper, and wood chemicals.
- develop improved techniques for engineering and using wood products in construction and in other applications. This topic includes development of improved methods for extending the service life of wood products by wood preservatives or other methods.
- develop new technology for using wood waste materials for energy or other purposes, and for minimizing water and air pollution.
- develop new or improved products and uses, such as laminates or wood chemicals, to enhance values of available wood resources and related benefits to society.
- develop improved technology and equipment for timber harvest and transport systems which will be more efficient and environmentally acceptable; especially for use in mountainous areas, including such logging systems as skyline, highlead, balloon, or helicopter.
- develop more efficient technology and equipment for regeneration of timber and forage, for related silvicultural operations, and for watershed and recreation area management.
- improve planning of forest road systems, locations and standards, to provide both efficient transportation and minimum impact on the forest environment.

International Forestry

The Forest Service also provides leadership and cooperation with forestry organizations and scientists throughout the world, together with such cooperative services as the training of foreign nationals and the furnishing of information, services, and tree seeds.

The Forest Service also cooperates with the U.S. Agency for International Development (AID) and the U.S. Department of Agriculture, Office of International Cooperation and Development (OICD), to help developing countries with forest, range, and watershed projects.

A Forestry Support Program provides technical assistance to AID's natural resource projects worldwide and to Peace Corps foresters, helping to design, execute, and evaluate a wide range of field projects.

The Forest Servicc, along with universities and other United States research organizations, also cooperates in various joint research projects with foreign members of the International Union of Forest Research Organizations (IUFRO). Participation in the work of the North American Forestry Commission, organized by the Food and Agriculture Organization of the United Nations, similarly involves studies and interchange of information on a wide range of forestry problems.

Forest Service Research Administration and Organization

The Forest Service Research Program is directed at the national level by a Deputy Chief of the Forest Service for Research. This Deputy Chief and headquarters staff have responsibility for the formulation and administration of national programs of forestry and range research by the Forest Service; for coordination with other research agencies in the U.S. Department of Agriculture, states, and other organizations; for investigations of national and international problems; and for program review and overall direction of the work carried out at Regional Forest Experiment Stations and other centers of Forest Service research.

Most of the Forest Service research program is carried out through a system of Regional Forest Experiment Stations located at:

Asheville, NC	Ogden, UT
Berkeley, CA	Portland, OR
Fort Collins, CO	St. Paul, MN
New Orleans, LA	Broomall, PA

The Forest Products Laboratory is located at Madison, WI.

Forestry and related investigations are conducted at 76 different centers of Forest Service research. Most of these are located on or near the campuses of cooperating universities. Some 83 experimental forests and ranges are used for studies of representative plant and animal communities. Research is also conducted on 150 research natural areas, and on numerous experimental sites on the lands of public, industrial, or other cooperators.

Several State forest products laboratories also supplement the work of the Forest Service's Forest Products Laboratory at Madison, WI, the national center for research on wood and wood products.

Forest and range management and utilization involves complex technical and economic factors; most problems in the field arise from multiple and competing demands for various products and services. Recognizing the consequent need for multidisciplinary studies, the Forest Service employs a wide spectrum of trained scientists in the biological, physical, chemical, economic, and social fields.

The scope of this effort is suggested by the fact that in 1988 the Forest Service carried on 713 scientist-years of research. At some 61 state universities and land grant colleges conducting forestry related research, there were 630 additional nonfederal scientist-years of research on forestry and associated range problems. Related research, in genetics and physiology for example, also contribute to the relevant pool of knowledge of various aspects of forestry and range problems. Industrial and other research organizations employ additional scientists to conduct investigations on forestry and range problems.

Competitive Grants

Part of the research carried on outside the Forest Service is funded by Competitive grants. The Forest and Rangeland Renewable Resources Research Act of 1978[9] authorizes the Secretary of Agriculture to make competitive grants to federal, state, and other governmental agencies, public or private agencies, institutions, and universities. Two chief objectives of the competitive grants program are to support fundamental research to promote the advancement of scientific wood utilization, and to further knowledge of biological mechanisms of forest organisms and their ecological relationships which contribute to the health and productivity of forest resources.

The Competitive Research Grants Office of the USDA's Cooperative State Research Service administers the program. Scientists selected from the research community serve as program managers or members of peer-review panels. Federal employees serve as associate program managers.

Procedures for awarding grants are based on a competitive evaluation process similar to that used by the National Science Foundation, a process concerned primarily with the scientific merit of a proposal. In 1987, 83% of the funds went to principal investigators working at colleges and universities, 14% to principal investigators with the Forest Service, and 3% to principal investigators in private industry. Often, scientists from different institutions cooperate on research projects.

Joint Planning and Coordination of Research

With the expansion of forestry and range research programs in the Forest Service and in state research agencies, there has been increasing recognition of the need for coordinated planning and cooperation in research projects. To this end, joint research planning efforts are carried on by the U.S. Department of Agriculture agencies and the National Association of State Universities and Land Grant Colleges to direct and provide balance in agricultural and forestry research programs.

As a further means of promoting coordination of related research activities, the Department of Agriculture in cooperation with states and other agencies has developed a computer-based information system that provides data information on active agricultural and forestry research of both federal and state research agencies. Use of this system helps avoid duplication and facilitates coordination of related research projects.

Another device to coordinate and apply related research efforts is illustrated by a recent (1974-80) forest pest research and land development program in which several USDA agencies, several universities, and state forestry organizations pooled resources to develop and test new technology for suppressing three major insect pests: the gypsy moth, the Douglas-fir tussock moth, and the southern pine beetle. Other research has been developed and carried out through research consortiums involving several universities and the Forest Service.

The state forestry departments also cooperate in various aspects of the Forest Service research program. Of particular importance is state cooperation in the testing and development of fire fighting technology, and in financial or other participation in the periodic forest surveys and resource assessments that are conducted by the Forest Service.

Relationships with Other Forest Service Programs

Within the Forest Service, the research program is closely coordinated with related programs for management of the National Forest System and Cooperative Forestry Assistance Programs with states and private forest owners and operators. All branches of the Forest Service participate in research to help solve forestry and range problems. Research scientists and National Forest System personnel often cooperate in the installation of studies on experimental forests or other National Forest System and private lands. Pilot tests and field application of new technology by State and Private Forestry personnel also supplement the work of research staffs.

New technology and other research findings are transferred through issuance of a wide variety of research publications and such other devices as symposia and field demonstrations on specific problems and subjects. Prompt application of research findings is facilitated by close association of researchers with National Forest System staffs, state forestry agencies, forest industries, and conservation organizations. Research activities also are linked with other major programs of the Forest Service through the Resources Planning Act process of long-range planning and program budget development.

Although the Forest Service has long been responsible for a major portion of publicly financed forestry and associated range research in the United States, federal, state, and private organizations also conduct or support research in forestry and rangeland management and utilization or closely related fields. Of particular importance, in this respect, is a coordinated federal-state program of research involving state agricultural experiment stations and forestry schools. Other agencies in the Department of Agriculture and other Departments also conduct or support some forestry or related research. The forest industries similarly play a major role in research and development dealing with the processing, marketing, and use of forest products and, to a more limited extent, with management of forest resources.

Cooperative research and memoranda of understanding are of considerable importance in correlating the research work of the Forest Service with that of other organizations, particularly the state universities and other United States Department of Agriculture agencies. The Forest Service provides cooperative grants and contracts for research by other federal, state, or private organizations in cases where special skills can be enlisted to help solve forestry problems. In fiscal year 1987, some 514 research agreements were made by the Forest Service: 437 with colleges and universities, 15 with nonprofit research institutions, 15 with federal, state, and local governments, and the remaining 47 with industrial or other private researchers. Twenty eight of the grants were for small business innovation research. Forest Service funds used for these studies totaled $14.6 million.

Conversely, a significant amount of Forest Service Research on a variety of problems is conducted under cooperative agreements with funding from other agencies such as the Environmental Protection Agency, the National Aeronautics and Space Administration, the Department of Energy, and private organizations.

Relationships with State Agricultural and Forestry Institutions

For many years, state agricultural experiment stations and forestry schools have conducted agricultural and forestry research with federal funding authorized in the Agricultural Experiment Station Act of 1887, commonly known as the Hatch Act.[10] This program has included many studies related to forestry and range management and use, although limited funds have been allocated for specific forestry projects.

The Cooperative Forestry Research Program Act of 1962, commonly known as the McIntire-Stennis Act,[11] provided the legislative basis for expanded federal funding of state institutions for research specifically related to forestry and related rangeland problems. Under this Act, federal funds are made available through the U.S. Department of Agriculture's Cooperative State Research Service to help in carrying programs of forestry research at (a) land grant colleges or agricultural experiment stations, and (b) other state-supported colleges and universities offering graduate training in the sciences basic to forestry and having a forestry school.

The McIntire-Stennis allotments now support research at 61 state agricultural experiment stations and forestry schools. Estimated funding in fiscal year 1988 included $17.5 million of federal funds. Nonfederal research funds available to the states for forestry and related research in this program have been about five times the federal allotments.

Apportionment of available federal funds among participating states is determined by the Secretary of Agriculture after consultation with a national council. The council is comprised of representatives from federal and state agencies concerned with developing and utilizing the Nation's forest resources, the forest industries, the forestry schools of the state-certified eligible institutions, state agricultural experiment stations, and volunteer public groups concerned with forests and related natural resources.

The broad definition of research in the McIntire-Stennis Act embraces investigations relating to management of forest and related range and watershed lands for the production of timber, livestock, forage, wildlife habitat, water and recreation, as well as to the harvesting, utilization, and marketing of forest products.

Additional authorizations for federal assistance to state and other research institutions have also been provided in other laws, including the Granger-Thye Act of 1950.[12] This Act sought to use the talents of university and other scientists in cooperation with Forest Service researchers. "Coop aid" grants are advanced to other institutions from Forest Service research appropriations for mutually agreed-upon investigations.

The Research Grants Act of September 6, 1958[13] also authorized federal agencies to enter into contracts for basic scientific research and to make grants for the support of such research. The Food and Agriculture Act of 1977[14] authorized grants to colleges and universities for research relating to production and marketing of alcohol and industrial hydrocarbons from agricultural commodities and forest products, together with loans for pilot plants for production of these products.

Relationships with Other USDA Agencies

Other agencies in the U.S. Department of Agriculture also conduct research or other investigations that are closely related to the research program of the Forest

Service. These activities are coordinated by formal memoranda of agreement, joint budget analyses and planning, project reviews, and on a variety of informal working arrangements among scientists.

Agricultural Research Service.—The comprehensive program of the Agricultural Research Service, dealing for example with such complex problems as photosynthesis, plant genetics, and plant physiology, provides knowledge that can be applied more or less directly to forestry and range problems. Other related investigations include:

- Investigations to improve range forage by breeding, selection, and testing of forage plants, by range fertilization and by range grazing practices. The Forest Service is assigned responsibility for research on management of ranges for livestock and wildlife, including both "forest ranges" and adjacent or associated nonforest ranges, i.e., rangelands commonly used by the same animals that use forest lands.

- Research relating to the culture of trees and shrubs for ornamental purposes, the culture and genetic improvement of lawn and street trees, the culture of farmstead windbreaks, and studies to evaluate environmental impacts of "field" shelterbelts. The Forest Service is assigned responsibility for establishment, management, and protection of native or introduced forest trees in forest areas, in "field" shelterbelts, and in urban and suburban areas.

- Research on soil and water management, largely oriented to agricultural watersheds but also including investigations related to Forest Service watershed research of forests and associated lands. Among these are studies of strip mine reclamation, including effects of using fertilizers and industrial wastes.

National Agricultural Pesticide Impact Assessment Program.—The Forest Service, along with the Agricultural Research Service, the Animal and Plan Health Inspection Service, the Economics, Statistics and Cooperative Service, and the Office of the General Counsel, provides scientific expertise and other support to the United States Department of Agriculture/States/ Environmental Protection Agency assessment teams. Together, they compile use, exposure, and benefits information on pesticides subjected to EPA's Rebuttable Presumption Against Registration (RPAR). The information is provided to the Environmental Protection Agency in a formal report transmitted to them by the Secretary of Agriculture.

Soil Conservation Service.—Resource surveys, assessments, and watershed investigations conducted by the Soil Conservation Service are closely related to the forest surveys and renewable resource assessment conducted by the Forest Service. The Forest Service cooperates with the Soil Conservation Service in these programs.

Nationwide data on soils, water, and related resources are collected by the Soil Conservation Service as a basis for periodic status reports on erosion and land treatment needs. The National Resource Inventory (NRI) is updated periodically to provide a nationwide inventory of resources including land/cover use, soil erosion, potential cropland, conservation needs, land capability, water bodies and streams, flood prone areas, conservation practices, riparian vegetation, pasture land conditions, rangeland condition, and other vegetation data.

The National Cooperative Soil Survey also provides basic data on kinds of soils in each county or other designated areas, together with data on limitations and potentials for alternative uses. The Soil Conservation Service has national leadership for this Soil Survey program but works in cooperation with land grant colleges and universities, with the Forest Service for soil surveys on the National Forest System lands, and with other organizations.

The Soil and Water Resources Conservation Act of 1977[15] authorizes the Secretary of Agriculture through the Soil Conservation Service to conduct periodic appraisals of the soil, water, and related resources of the Nation, and to evaluate and develop resource conservation programs. The Act is a companion measure to the Forest and Rangeland Renewable Resource Planning Act of 1974[1] administered by the Forest Service. These two laws direct the U.S. Department of Agriculture to make a total assessment of America's renewable natural resources and to develop programs that will protect and improve these resources.

The Soil and Water Resources Conservation Act of 1977 is aimed at furthering the conservation of soil, water, and related resources by:

1. Appraising on a continuing basis the condition and problems of soil, water, and related resources of the Nation.

2. Developing and updating periodically a program for furthering the conservation and enhancement of soil, water, and related resources, consistent with the roles and program responsibilities of other federal agencies and local and state governments...

Under the provisions of the Soil and Water Conservation Act the appraisal and program must include:

- the nature and extent of soil, water, and related resources in the United States, including fish and wildlife habitat.

- the capability and limitations of these resources for meeting current and projected demands on the resource base.

- the effectiveness of continuing soil and water conservation programs, laws, and policies.

- evaluation of alternative methods for the conservation, protection, environmental improvement, and enhancement of soil, water, and related resources.

- the costs and benefits of alternative soil and water conservation practices.

- investigation and analysis of the practicability, desirability, and feasibility of collecting organic waste materials, including logging and wood manufacturing residues.

Various measures have been adopted to assure close coordination of Forest Service and Soil Conservation Service activities relating to resource assessments and program evaluations. Thus, a joint Soil Conservation Service/Forest Service liaison committee has been established to coordinate the basic assumptions and data used in the appraisal and assessment.

Other agreements have been developed between the Forest Service and the Soil Conservation Service; the Economics, Statistics and Cooperatives Service; and the Bureau of Land Management; and the Fish and Wildlife Service in the Department of the Interior to provide for coordinated development of needed techniques for multiresource inventories, land classification, and resource evaluations.

In both the Forest Service and Soil Conservation Service programs of resource assessment and program development, public participation is solicited from landowners and operators, conservation and environmental organizations, state forestry agencies, and other concerned people and groups.

The Soil Conservation Service has leadership responsibility for watershed surveys and investigations that cover forests and rangelands and other agricultural and related resources. These investigations are conducted in cooperation with other agencies in the Department of Agriculture and with other federal and state agencies.

Much of the work on river basin surveys and investigations is conducted under the Watershed Protection and Flood Prevention Act of 1954,[16] commonly referred to as the P.L. 566 Program. This Act provided for cooperative surveys and investigations of specified river basins to serve as a guide for agricultural and other rural development programs. Forest Service cooperation with the Soil Conservation Service includes responsibility for the "forestry aspects" of river basin planning for both federal and nonfederal forest lands, for planning related to rangelands within or adjacent to the National Forest System, for analyses and projections of economic activity relating to multiple uses and industrial or other production from forest lands, for appraisals of the capability of forest lands to meet future demands for goods and services, and for estimates of amounts and costs of forest conservation practices. This participation in investigations and planning is supplemented by participation in related resource action programs referred to in the following section on Cooperative Forestry Programs.

The Soil Conservation Service has responsibility for inventories of forage resources on most nonfederal lands. The Forest Service conducts range inventories on the National Forest System. It is the policy of both agencies to coordinate resource inventories, jointly determine data needs and procedures, avoid duplication, and assure that data collected are mutually usable.

Economic Research Service.—This agency conducts investigations dealing with the conservation and development of natural resources and their contribution to local, regional, and national economic growth. It also has responsibility for research in range economics and other agricultural economics research. Cooperation with the Forest Service includes analyses of demand for livestock and grazing uses used in preparing renewable resource assessments. Studies are also conducted in coordination with the Soil Conservation Service and the Forest Service in river basin and related water investigations, and in other intradepartmental studies such as pesticide impact evaluations.

The National Agricultural Statistics Service (NASS) cooperates with State agencies in reporting prices of timber and timber products.

Relationships with Other Federal Agencies

The Forest Service has long cooperated with other federal agencies, particularly in the Department of the Interior, to help assure coverage by Forest Service research scientists of problems that are of concern to these other agencies. A portion of this Forest Service research effort, conducted for the most part at western Forest Experiment stations, has been financed by these cooperating agencies. Other research on forest and rangeland problems also is conducted or supported by these other federal agencies, as indicated below.

Bureau of Land Management.—The Bureau of Land Management in the U.S. Department of the Interior supports a limited program of research and development projects relating to forests and rangelands under authorizations in the Federal Land Policy and Management Act of 1976.[17] Studies are largely conducted

through cooperative agreements with universities and federal research agencies. These studies largely involve problems encountered in the management of federal lands relating to watershed protection, timber production, range forage production, wildlife habitat improvement, and rehabilitation of lands damaged by fire. Inventories of range, timber, and other resources on lands under the administration of the Bureau of Land Management also are conducted by the agency as a basis for management programs. As with other land management agencies, many environmental analyses also are prepared for "major" activities, as required by the National Environmental Policy Act of 1969.[18]

National Park Service.—The Park Service conducts studies concerning the development and management of outdoor recreation and the associated land and water resources. These supplement Forest Service work and contribute to the management of outdoor recreation and the Forest Service preparation of renewable resource assessments and programs.

Fish and Wildlife Service.—This agency conducts biological and economic research on fish and wildlife problems. Cooperation with Forest Service research is provided for in cooperative agreements under which the Fish and Wildlife Service emphasizes the animal phases of problems while the Forest Service emphasizes the vegetation and land use or habitat phases. Cooperative studies of wildlife and habitat problems also are conducted by scientists from the agencies.

Other agencies.—Other federal agencies also conduct or finance forestry or forest-related research that supplements the research efforts of the Forest Service.

The *Geological Survey* in the U.S. Department of the Interior administers a cooperative program of contracts and grants with University Water Resources Research Institutes, under the Water Resources Research act of 1974.[19] Related responsibilities of this agency include the transfer of technology relating to water resources of federal water research.

The *Environmental Protection Agency* finances a substantial program of cooperative research, including studies by the Forest Service and other research organizations. Examples of Environmental Protection Agency sponsored research in the Forest Service include studies concerning the effects of ultraviolet radiation on growth and development of forest trees, the impact of air pollutants on forests, problems of water quality and reclamation of strip-mined areas, assessments of technology for determining water pollution from forested watersheds, and the development of management guides for minimizing nonpoint source pollution in forested areas.

The *National Science Foundation* provides some grants for research projects which relate to forestry and range problems. The Tennessee Valley Authority conducts studies of regional problems of forest management and utilization. The National Aeronautics and Space Administration has financed both university and Forest Service research to improve methods for remote sensing of natural and artificial resources. The Department of Housing and Urban Development has allotted funds to the Forest Service for housing research. The Department of Energy has funded Forest Service studies of forest residues and opportunities for production of energy from wood material.

Relationships With Industrial Research Agencies

Research by the forest industries, particularly the pulp and paper industry, directly complements the Federal-State forest research programs, chiefly in investigations concerning the processing, marketing, and consumer use of wood products. Other industries, such as the chemical and machinery industries, also conduct research that is of benefit in the solution of certain forestry or range problems. Much of the industrial research is related to product development and is proprietary.

Industry usually looks to public research organizations such as the Forest Products Laboratory and universities for more basic investigations. It also cooperates with the Forest Service in many research areas such as forest protection, tree improvement, and forest productivity.

Relationships With the General Public

Public involvement in forestry and range research programs is achieved, in part, using advisory committees by the Department of Agriculture, the Forest Service, universities, and other research agencies and organizations. Thus, the Food and Agriculture Act of 1977[14] directed the Secretary of Agriculture to establish a Joint Council on Food and Agricultural Sciences to foster coordination of the agricultural research, extension, and teaching activities of the Federal Government and other institutions. This Act also provided for a National Agricultural Research and Extension Users Advisory Board to review policy, plans, and goals of programs for agricultural research and extension, and to provide recommendations regarding program responsibilities and funding.

Regional Experiment Stations of the Forest Service have used advisory committees, composed of representatives of state agencies, forest industries, and other groups concerned with forestry and related problems, to review current and proposed research. As noted earlier, an advisory committee provides counsel and advice to

the Secretary of Agriculture in carrying out the McIntire-Stennis forestry research program.

Panels of industry representatives are consulted periodically to review and help coordinate planned research on timber utilization problems at the Forest Products Laboratory and at other utilization research centers. Special committees of experts and concerned organizations are sometimes formed to coordinate research by different agencies on such problems as use of pesticides, range brush control, or other problems of land management.

The use of such committees, panels and groups represents a part of a general effort by the Forest Service to obtain broad public involvement to guide the formulation and conduct of forestry and related resource programs.

COOPERATIVE FORESTRY PROGRAMS

Forests and rangelands in private and nonfederal public ownerships constitute the major part of the Nation's 1.5 billion acres of forests and rangelands. Of the total area of some 483 million acres of timberland, for example, 57% is in nonindustrial private ownerships, including farmers and a wide variety of other people. About 15% of the timberland is owned by forest industries, and 7% by states and local governments. Much of the remaining forest land which is more suitable for uses other than timber production, and most of the Nation's rangeland, is also in private ownership.

The nonindustrial private and nonfederal public lands provide more than half of the timber harvested in the United States. Industrial forest lands furnish nearly 30% of the total. These private lands also provide major portions of livestock grazing, hunting and other outdoor recreation, and water supplies. Most of these lands are of high site quality and are favorably located for protection of timber and for other uses.

Despite these favorable factors, there have been problems in maintaining and increasing timber supplies. In the United States, the economy largely relies on a system of markets and prices to bring about changes in the supplies of goods and services. For timber, however, the problem and the basic obstacle to increasing and extending supplies is that this system does not work very well.

This may be due, in large part, to market imperfections in the forestry sector. The market system that so effectively guides the production of most goods and services responds in only a limited way to increasing timber supplies. The best quantitative measure of market imperfection for timber supplies is the coefficient of price elasticity of supply. This coefficient is a measure of the percentage change in stumpage (timber) supply resulting from a percentage change in stumpage prices.

For example, with a 10% increase in stumpage prices, if stumpage supplies increase 3%, the coefficient of price elasticity would be 0.3. In simpler terms, it is a measure of the responsiveness of forest owners to price changes. The further the coefficient falls below 1.0, the more unresponsive or imperfect the market. The best data shows that for each 10% increase in stumpage prices there is less than a 4% increase in supplies.

There are five major causes of imperfections in timber markets:

1. The short time-preference of individual landowners which constrains investments in management options yielding rewards after an extended period of time.

2. Lack of investment capital and market and management knowledge among private timber owners.

3. Ownership objectives which limit or constrain timber production.

4. Limited competition among timber buyers.

5. Failure of the stumpage market price to reflect all benefits associated with the forest such as the provision of wildlife habitat, scenic beauty, and improved water quality, as well as costs such as the pollution resulting from the use of chemicals and fires.

The market system also has no means of adequately recognizing societal interests in the protection of the forest investment, and in the maintenance of the resource base and the productive capability of forest lands.

Authorization for Cooperative Programs

In the past, society has taken action to increase timber supplies by supplementing market forces through various kinds of legislation and funding of programs including those of protection and technical and financial assistance for nonindustrial forest owners. Alternative courses of actions such as federal regulation of the use and management of private forests have not been generally accepted by society as a means of achieving intensified management and enhanced productivity and increased timber supplies.

Gifford Pinchot proposed a federal program to help forest owners in the management of timberlands as early as 1898. Shortly after he took office as the first Chief of the Division of Forestry (now the Forest Service), Circular 21, "Practical Assistance to Farmers, Lumbermen,

and Other Owners of Forest Land," was issued, beginning the first of many efforts in federal cooperative forestry.

For many years, however, the assistance offered to private timberland owners and operators was very limited. The Weeks Law of 1911[20] authorized cooperation with the states in forest fire control on private and state lands. The Smith-Lever Act of 1914[21] provided for a cooperative system, including the U.S. Department of Agriculture, state land grant colleges and universities, and county extension services, to extend results of research to farmers and other rural people.

In 1924, the Clarke-McNary Act[7] provided further authorization for cooperative fire control and authorized federal funding on a matching basis with the states to aid farmers by providing information on management and utilization of forest resources. This Act stimulated the appointment of the first full time professional foresters providing assistance to private timberland owners.

In 1937, the Norris-Doxey Cooperative Farm Forestry Act[22] provided some federal funding and direct technical assistance to individual farm woodland owners and for extension education. During World War II, the Forest Service also established a forest utilization service at forest experiment stations to help improve sawmill operations, help locate timber for special needs, and otherwise help the war effort.

The Cooperative Forest Management Act of 1950[23] greatly strengthened the technical forestry assistance programs conducted by state forestry organizations and the Forest Service. This Act broadened the program to include all private landowners, forest operators, wood processors, and public agencies with respect to multiple-use management of forest lands, the utilization of forest products, and urban forestry.

Title IV of the Rural Development Act of 1972[24] authorized a cooperative Rural Community Fire Protection program to help rural towns and communities of less than 10,000 population to acquire needed firefighting equipment and to train firefighting personnel.

Finally in 1978, the Cooperative Forestry Assistance Act[25] consolidated and expanded the authority for federal assistance on nonfederal forest lands. It authorized the Secretary of Agriculture to cooperate with state foresters or equivalent state officials in providing this assistance.

Scope and Goal of Cooperative Forestry Legislation

The goals under this legislation, for nonfederal lands, are to assist in:

- the advancement of forest resources management;
- the production of timber;
- the encouragement of prevention and control of insect and diseases affecting trees and forests;
- the prevention and control of rural fires;
- the efficient utilization of wood and wood residues including the recycling of wood fiber;
- the improvement and maintenance of fish and wildlife habitat; and
- the planning and conduct of urban forestry programs.

The scope of the programs authorized under the legislation are quite broad. They include:

Rural forestry assistance.—Under the rural forestry assistance provisions of the Act, the Secretary is authorized to provide financial, technical, and related assistance to state foresters to:

- develop genetically improved tree seeds.
- procure, produce, and distribute tree seeds and trees to establish forests, windbreaks, shelterbelts, woodlots, and other plantings.
- plant tree seeds and trees for the reforestation or afforestation of nonfederal forest lands suitable for production of timber and other benefits associated with the growing of trees.
- plan, organize and implement measures on nonfederal forest lands, including but not limited to, thinning, prescribed burning, and other silvicultural practices designed to increase the quantity and improve the quality of trees and other vegetation, fish and wildlife habitat, and water yielded therefrom.
- provide technical information, advice, and related assistance to private forest landowners and managers, vendors, forest operators, wood processors, public agencies, and individuals regarding the:
  - harvesting, processing, and marketing of timber and other forest resources, and the marketing and utilization of wood and wood products;
  - conversion of wood to energy for domestic, industrial, municipal, and other uses;
  - management planning and treatment of forest land, including, but not limited to, site preparation, reforestation, thinning, prescribed burning, and other silvicultural practices

- designed to increase the quantity and improve the quality of timber and other forest resources;

- protection and improvement of forest soil fertility and the quality, quantity, and timing of water yields; and

- effects of forestry practices on fish and wildlife and their habitats.

Forestry incentives.—Section 4 of the Act authorizes the Secretary to develop and implement forestry incentive programs to encourage landowners to:

- apply practices that will provide for afforestation of suitable open lands;
- reforest cutover or other nonstocked or understocked forest lands;
- implement timber stand improvement practices including thinning, prescribed burning, and other silvicultural treatments; and
- improve forest management and protection.

Insect and disease control.—The insect and disease control provisions of the Act authorize the Secretary to:

- conduct surveys to detect and appraise insect infestation and disease conditions affecting trees;
- determine the biological, chemical, and mechanical measures necessary to prevent, retard, control, or suppress incipient, potential, threatening, or emergency insect infestations and disease conditions affecting trees;
- plan, organize, direct, and perform measures necessary to prevent, retard, control, or suppress any incipient, potential, threatening, or emergency insect infestations and disease epidemics affecting trees;
- provide technical information, advice, and related assistance in managing and coordinating the use of pesticides and other toxic substances applied to trees and other vegetation, and to wood products, stored wood, and wood in use; and
- take any other actions the Secretary deems necessary to protect from insects and diseases trees and forests, wood products, stored wood and wood in use.

Urban forestry assistance.—Cooperative urban forestry assistance began in 1972 when the Cooperative Forest Management Act of 1950[23] was amended to include urban forestry. Funds were first appropriated for urban and community forestry in fiscal year 1978. Section 6 of the Cooperative Forestry Assistance Act established the Urban Forestry Assistance Program. This authorizes financial, technical, and related assistance to state foresters to provide information and technical assistance to units of local government and others that will encourage cooperative efforts to plan urban forestry programs and to plant, protect, maintain, and use trees in open spaces, greenbelts, roadside screens, parks, woodlands, curb areas, and residential developments in urban areas. Direct cooperation with local governments is also authorized if the state forester agrees that would better achieve the goals of the Act.

Rural fire prevention control.—Under the rural fire prevention and control provision of the Act (Sec. 7) the Secretary has authority under whatever conditions he may prescribe, to:

- cooperate with state foresters in developing systems and methods for the prevention, control, suppression, and prescribed use of fires on rural lands and in rural communities that will protect human lives, agricultural crops and livestock, property and other improvements, and natural resources;
- provide financial, technical, and related assistance to state foresters and through them to other agencies and people, for the prevention, control, suppression, and prescribed use of fires on nonfederal forest lands and other nonfederal lands; and
- provide financial, technical, and related assistance to state foresters in cooperative efforts to organize, train and equip local firefighting forces, including those of Indian tribes or other native groups, to prevent, control, and suppress fires threatening human lives, crops, livestock, farmsteads or other improvements, pastures, orchards, wildlife, rangeland, woodland, and other resources in rural areas.

The Act also provides for the establishment of a special rural disaster fund to be used in rural fire emergencies.

Management assistance, planning assistance and technology implementation.—Section 8 of the Act authorizes:

- financial, technical, and related assistance to state foresters for the development of stronger and more efficient state organizations including matters related to organization management, program planning and management, budget and

fiscal accounting services, personnel training and management, information services, and recordkeeping.

- financial, technical, and related assistance to state foresters in the assembly, analysis, display, and reporting of state forest resources data; in the training of state forest resources planners; and in participating in natural resources planning at the state and federal levels.
- a program of technology implementation to ensure that new technology is introduced, new information is integrated into existing technology, and forest resources research findings are promptly made available to potential users.

Forest Service Responsibilities for Cooperative Forestry Programs

Several agencies in the Department of Agriculture have important responsibilities in carrying out the cooperative forestry programs authorized by the Cooperative Forestry Assistance Act and the other related legislation. The Forest Service, through its branch of State and Private Forestry, provides leadership in land and resource protection on both nonfederal and federal lands. In addition the Forest Service has the responsibility for carrying out prevention and suppression activities directly on federal lands and providing assistance for these activities on state and private lands. It also provides leadership for a coordinated fire protection network composed of federal, state, and private fire organizations which can be quickly mobilized to combat wildfires.

The Forest Service works cooperatively with state forestry organizations to provide land management assistance to owners of nonindustrial forest lands. It also coordinates with the many agencies and organizations whose programs affect private forest lands in this country. The State and Private Forestry branch co-chairs a Private Forestry Issues Working Group within the U.S. Department of Agriculture that coordinates all the Department's programs that deal with private forest lands. This branch also has the lead responsibility for transferring new and existing knowledge, information, or capabilities both inside and outside the Forest Service to improve forest resource management, utilization, and protection.

Table 2.—Forest Service funds for cooperative forestry programs, fiscal year 1988.

Program	Funds *(thousand dollars)*
Appropriated funds:	
Forest Pest Management	44,441
Fire Protection	13,770
Forest Management and Utilization	10,783
Special Projects	10,875
Subtotal	79,869
Transfer funds:	
Rural Community Fire Protection	3,091
Watershed and Flood Prevention	2,777
Watershed Planning and Operations	241
River Basin Surveys and Investigations	852
Resource Conservation and Development	803
Forestry Incentives Program	1,189
Agriculture Conservation Program	1,769
Pesticide Assessment	369
Subtotal	10,722
Total, Appropriated and Transfer Funds	90,591

[1]*Initial allocations subject to increases depending upon Conservation Reserve sign ups and emergencies.*

Forest Service Cooperative Forestry Program Areas

There are active State and Private Forestry programs in the following five areas: forest pest management, fire protection, forest management and utilization, special projects, and transfer programs. The funding available for these programs in fiscal year 1988 is shown in table 2. Congress appropriates funds to the Forest Service for the first four categories. The Soil Conservation Service and other federal agencies provide funds for the transfer programs.

Forest Pest Management

The basic purpose of the Forest Pest Management program is to help land managers protect forest resources from insects and diseases on all forested lands—federal, state and private. The program provides for surveys and technical assistance, suppression and special projects for technology transfer.

The Forest Service conducts surveys to detect and evaluate pest populations or vegetative damage on National Forest and other federal lands. State forestry organizations conducts similar surveys on private lands. The affected land managers are provided the results, along with advice and recommendations about suppression options.

The Forest Service pest management specialists provide technical assistance to federal land managers and to state pest management specialists through consultation, seminars and workshops. The assistance covers a range of problems from survey techniques to pest identification, as well as pesticide selection and application. Furthermore, the state pest management specialists

provide technical assistance to state and private land managers. In recent years the major pest-suppression projects were directed at gypsy moths, Southern pine beetles, western spruce budworms, dwarf mistletoes and mountain pine beetles.

Special projects for technology transfer cover a variety of subjects. In fiscal year 1988, special projects have been undertaken on southern pine beetle management; acid deposition assessments; gypsy moth control; training of federal employees in the handling, application, storage and disposal of pesticides; and the National Agricultural Pesticide Impact Assessment Program.

Fire Protection

The Forest Service's Cooperative Fire Protection Program aims to improve the efficiency and effectiveness of wildland fire protection by providing assistance to the states. Several types of assistance are provided: training, information gathering and dissemination, technical expertise, coordination and equipment.

The Cooperative Fire Protection Program is made up of several parts: rural fire prevention and control, rural community fire protection, federal excess personal property, Smokey Bear Program, federal disaster assistance, wildland/urban interface fire protection initiative, and fire prevention.

Rural fire prevention and control.—The Rural Fire Prevention and Control Program provides for most of the funding to administer and carry out the Cooperative Fire Protection program. It also provides financial assistance to States for accomplishing tasks agreed to in regional plans that have been recognized as being in the national interest.

Rural community fire protection.—The Rural Community Fire Protection program is funded by Farmers Home Administration and is administered by the Forest Service and state foresters. It is intended to help strengthen volunteer fire departments in communities of less than 10,000 people. The funding is used for organizing, training and equipping rural fire departments. This program is important because without adequate local fire protection, the task of both wildland and structural fire fighting fall to state and federal wildland agencies.

Federal excess personal property.—This program provides for the recycling of excess federal equipment obtained from the military and other federal agencies, including the Forest Service. Items are loaned to state forestry agencies for use in wildfire protection. States will either use them directly or may redistribute them to rural fire departments. These items remain the property of the Federal Government with the Forest Service retaining title. Some items may be usable as is, while others may require extensive reconditioning or modification. Typical is the conversion of excess military truck chassis for use as fire trucks.

Smokey Bear program.—This program serves the needs of federal, state and local governments engaged in wildland fire prevention. It is a public awareness program with a simple message appealing to a broad audience—"Only You Can Prevent Forest Fires." The message may take many forms often aimed at youth.

Federal disaster assistance program.—This program provides assistance to the states for emergency fire suppression when life and property are threatened in an extreme fire emergency. The program is administered and funded by the Federal Emergency Management Agency (FEMA). Usually, Forest Service Cooperative Fire Protection personnel serve in a technical advisory capacity to FEMA during emergency situations.

Wildland/urban interface fire protection initiative.—Beginning early in 1986, the Forest Service forged a partnership with other federal agencies, the National Fire Protection Association, and the National Association of State Foresters for the specific purpose of tackling the growing wildfire threat in what has become known as the wildland/urban interface. The intent is to reduce the potential fire hazard associated with the increasing number of homes in areas where forest and homes intermingle. As population and the desire to live in natural settings have increased, so has the fire threat. The program seeks to educate the public about the problem, stimulate State and local governments to implement preventive measures, and provide professional expertise in this area for creating a more fire-safe environment.

Fire Prevention.—Both the Smokey Bear program and the Wildland/Urban Interface Fire Protection Initiative are major components of fire prevention, but a further crucial aspect of the program is the prevention of fire starts in all areas of the forest and wildlands. Little can be done to reduce natural causes such as lightning ignitions; however most fires are person-caused, and a large part of them are arson-related. Efforts are directed at identifying the causes and developing efforts to reduce them.

All the programs described are aimed at improving the states' ability to manage their fire problems. Fire protection on state and private land is basically a state and local responsibility. However, without adequate protection, the Federal Government is often called to provide assistance. A federal role is often necessary to efficiently transfer the latest technology, coordinate and encourage interstate cooperation, access national trends and disseminate information efficiently. It is also in the Federal Government's best interest to have reliable fire fighting forces available for extreme situations where federal forces are not adequate. This is required by the

variability in fire seasons. It is efficient for all emergency organizations to plan for the norm and to rely on outside cooperation and assistance when appropriate.

Forest Management and Utilization

In its cooperative management program, the Forest Service provides technical and financial assistance to state forestry organizations. These state organizations, in turn, provide technical advice to private landowners.

In the Utilization Program the Forest Service carries on a variety of activities concerned with the utilization and marketing of timber and timber products. It works with state forestry and other state and federal agencies to increase the export of timber products. It works to develop and introduce new technologies which use low quality timber, while improving the quality and composition of timber stands.

The Forest Service also works to develop and use technology such as microcomputer programs, for improving the efficiency of timber harvesting, wood processing and use. Additionally, it sponsors training workshops and conferences to improve market development. In addition it participates in rural development programs, including those that provide technical and financial assistance to rural landowners, communities, and forestry organizations, where there is the potential for increasing forest-based employment and income.

The Forest Service nursery and tree-improvement program provides technical and financial assistance to the states for upgrading the quality of seedings in their nurseries. This assistance is aimed at long-term investments and activities that protect soil and water resources while leading to more economical and productive reforestation of nonfederal lands.

The Urban and Community Forestry Program aims to improve the quality of life in communities through the planting and management of trees, shrubs, and other vegetation. Technical assistance is provided to communities through a partnership with state forestry agencies and professional organizations, such as the American Forestry Association, the National Urban Forestry Council, the National Association of State Foresters, the National Arbor Day Foundation, and the International Society of Arboriculture.

The Forest Service Statewide Forest Resource Planning Program provides technical and financial assistance to states for forest resources planning.

Special Projects

The Forest Service conducts several special projects as part of its State and Private Forestry programs. The Boundary Waters Canoe Area Wilderness Act of 1981[26] authorizes the Forest Service to cooperate with the State of Minnesota to intensify forest management on forest lands owned by the State, its counties and its private citizens. The Act seeks to mitigate the loss of timber production caused by incorporating forest lands in the State into the Boundary Waters Canoe Area.

The Burton-Santini Act authorizes the Secretary of Agriculture to make financial assistance grants to local governments within the Lake Tahoe Basin for the purpose of reducing soil erosion and water pollution.

As one of the special projects, the Forest Service manages as a National Historic Landmark the Grey Towers estate in Pennsylvania, former home of Gifford Pinchot, first chief of the Forest Service. Grey Towers houses the Pinchot Institute for Conservation Studies. The landmark maintains active programs for outreach to the public, interpretation of natural resources, and a historical presentation of Forest Service heritage through its link to the Pinchot family. Grey Towers' personnel also provide on-the-job experience in historic site management to other Forest Service employees and share their skills with community groups and state and local governments.

Transfer Funds

The preceding programs are carried out with funds directly appropriated to the Forest Service. There are other programs and activities administered with funds transferred from other agencies (table 2).

For example, the Forest Service administers the rural community fire protection program using funds transferred from the Farmer's Home Administration. Funds are made available to small rural communities to organize, train, and equip fire protection forces. Matching funds from states and community fund-raising efforts provide an efficient and effective rural fire protection resource.

The Forest Service provides technical leadership for the forestry aspects of the small watershed and flood prevention programs—The Watershed Protection and Flood Prevention Act of 1954[16] commonly referred to as P.L. 566, and the Act of December 1944[27] (P.L. 534). The Forest Service also handles emergency watershed protection projects including the treatment of hazards to life and property on National Forest lands. The Soil Conservation Service administers these programs.

The Forest Service is also responsible for the forestry provisions of the Resource Conservation and Development Program administered by the Soil Conservation Service. This program provides assistance to leaders of conservation and development areas in planning and implementing local forestry goals and objectives. The technical assistance includes such activities as feasibil-

ity studies, demonstrations and training, and the development of markets for timber products.

More detail on the Forest Service responsibilities and programs carried out with transfer funds follows under the discussion of relationships with other agencies.

Forest Service Cooperative Programs Administration and Organization

The Forest Service cooperative programs are directed at the national level by a Deputy Chief of the Forest Service for State and Private Forestry. This Deputy Chief and the supporting headquarters staff have the responsibility for formulation and administration of the cooperative programs at the national level; for coordination with other agencies in the U.S. Department of Agriculture, states, and other agencies and organizations; for international activities; and for program review and general direction of the work carried out at Forest Service regional offices and other centers in the field concerned with cooperative programs.

The Forest Service cooperative program responsibilities are carried out by an Area Director of Northeastern Area State and Private Forestry located in Broomall, PA and by regional foresters located at:

Missoula, MT	San Francisco, CA
Lakewood, CO	Portland, OR
Albuquerque, NM	Atlanta, GA
Ogden, UT	

Many of the state and private cooperative programs, especially those concerned with technology transfer, involve complex problems requiring a wide array of technical skills. The personnel involved have advanced training in biological, physical, educational, and social sciences.

In total, about 510 people were employed in the Forest Service State and Private programs, in 1987. Most of them were directly involved in some form of technology transfer. Many more state people were involved in the cooperative programs.

Relationships With Other Forest Service Programs

The cooperative forestry programs are closely integrated with the Forest Service research program and with administration of the National Forest System. In the transfer of technology from researchers to users of new knowledge, federal and state foresters and subject matter specialists are important links. They participate with research scientists and user groups in the selection of research projects and the planning of research. They conduct pilot tests of new techniques and materials on diverse subjects such as fire and insect control and improved wood utilization. They transfer technical information to a wide variety of owners, operators, and users of forest and range resources.

These cooperative forestry programs similarly have direct impacts on the protection and management of National Forest System lands that are typically interspersed with or adjacent to private or other nonfederal ownerships. Thus, cooperative programs of rural fire prevention and control are essential to protection of many lands in the National Forest System. State and Forest Service fire organizations have many reciprocal protection agreements, close working relationships, and frequent joint control efforts. The insect and disease control program likewise illustrates joint action by the Forest Service and state and other operators. In activities relating to watershed planning and flood control operations, State and Private Forestry specialists also work directly with National Forest System personnel in coordinated projects.

Relationships With Other Agencies

The Forest Service cooperative forestry programs represent a major part of federal assistance to promote and improve forestry on private and nonfederal public lands, but other agencies also have substantial responsibilities for related programs.

The Forest Service and the agencies conducting these related programs have developed many memoranda of agreement and other arrangements to assure program coordination and continuing cooperation in administering related activities. Within the Department of Agriculture, the Secretary provides delegations of authority to departmental agencies, guidelines for forestry planning and formulation of budget proposals, and definitions of agency roles in delivery of programs of education, technical assistance, and other forestry incentives.

Staffs of the Forest Service, the Soil Conservation Service, the Extension Service, the Agricultural Stabilization and Conservation Service, the Cooperative State Research Service, and the Farmers Home Administration work together in coordinating programs. These staffs also work closely with cooperating organizations that are directly concerned with forestry programs, including the National Association of State Foresters, the Association of Farmers Elected Committeemen, and the National Association of Conservation Districts.

The responsibilities of other agencies for cooperative forestry related programs are as follows:

Soil Conservation Service.—The Soil Conservation Service is assigned responsibility for several programs that apply to forests and rangelands to croplands, pas-

turelands, or other resources "related" to soil and water. A Secretarial delegation of authority to the Agency provides for "national leadership in the conservation, development and productive use of the Nation's soil, water and related resources."

Some of the activities for which the Soil Conservation Service has responsibility or leadership assignments are closely related to Forest Service research programs, and have been described in the preceding section dealing with forest and range research interrelationships. These include resource inventories and monitoring; national appraisals of soil, water and related resources; river basin surveys and investigations; and range inventories on nonfederal lands.

As part of its program of "conservation operations," the Soil Conservation Service, in cooperation with some 13,000 conservation districts, provides technical aid to farmers, ranchers, and other land users in planning and carrying out locally adapted soil and water conservation measures. This assistance, provided under the Soil Conservation and Domestic Allotment Act of 1936[28] is available in all 50 states, Puerto Rico, and the Virgin Islands. Conservation districts now cover some 97% of the Nation's farm and ranch lands. Thus, they include much of the private forests and rangeland that is also covered in cooperative Forest Service-state forestry programs, in Forest Service-university forest research programs, and to some extent in administration of the National Forest System.

Guidelines developed by the Secretary of Agriculture provide that the Forest Service in cooperation with state foresters, and the Soil Conservation Service in cooperation with conservation districts, have lead roles in the "service" component of technology transfer, including on-the-ground assistance to individuals as their primary clientele. Forestry assistance is provided by the Soil Conservation Service as a part of total technical assistance to private landowners and land users when such services are an integral part of land management and such services are not available from a state agency. The agency also provides forestry services concerning windbreaks and shelterbelts. In carrying out this technical assistance program, Soil Conservation Service technicians work directly with landowners and farm operators in developing conservation plans for farms, ranches, and other land units. They also help carry out recommended conservation practices, including such measures as planting trees shrubs or grass on eroding areas, thinning and other timber stand improvement, prescribed burning, improving grazing systems, wildlife habitat management, and recreation area improvement.

The Watershed Protection and Flood Prevention Act of 1954,[16] (P.L. 566) includes provisions for cooperation between the Federal Government, the states and local subdivisions in both planning and operations programs for the protection and improvement of individual watersheds not exceeding 250,000 acres. Planning assistance is provided in response to requests from local sponsoring organizations. The dominant objectives in this planning program have been watershed protection and flood prevention, but multipurpose projects can also include water supply, irrigation, outdoor recreation, and fish and wildlife habitat features.

In carrying out these local planning projects, the Soil Conservation Service is assigned the administrative leadership responsibility. The Forest Service is assigned responsibility for administering the forestry aspects of these projects on National Forest System lands, on adjacent lands administered by the Forest Service under formal agreement, and on nonfederal forest lands.

The Economic Research Service and the National Agricultural Statistics Service participate in this program by development of criteria and economic analyses of project plans. The Science and Education Administration conducts studies that are related to and used in watershed planning and action programs. State and local units of government also participate in watershed planning and provide about a third of the total costs of this watershed program.

Besides assistance in watershed planning, the U.S. Department of Agriculture also helps finance and install works of improvement and land treatment measures specified in individual watershed plans. These watershed operations are conducted under:

1. the Act of December 22, 1944[27] (P.L. 534), which provided for works of improvement for runoff and waterflow retardation and soil erosion prevention on 11 major watersheds.

2. the Watershed Protection and Flood Prevention Act of 1954[16] (P.L. 566), which provided for cooperation between the Federal Government and the states and political subdivisions in the installation of facilities and land treatment measures to prevent erosion, flood and sediment damage, further the development and utilization of water, and improve conservation and proper utilization of the land. Both works of improvement, and particularly the land treatment measures installed in the areas covered by these watershed projects, supplement other forestry and range programs conducted by the Forest Service and other federal and state agencies.

While the Soil Conservation Service has general responsibility, the "forestry aspects" of these programs are carried out by the Forest Service in cooperation with the

Soil Conservation Service and state foresters. Cooperative arrangements, outlined in memoranda and agreements between the Soil Conservation Service and the Forest Service, provide that the two agencies will jointly prepare an annual program activity plan and budget for the forestry aspects of watershed planning and operations, under general program criteria and procedures established by the Soil Conservation Service.

The Act of June 28, 1938[29] and various appropriation acts provide for emergency action where forest fires, floods, or other natural disasters have caused sudden impairment of watersheds. Emergency work includes such measures as reestablishment of trees or other vegetative cover on denuded lands, clearing stream channels, and land stabilization. The Soil Conservation Service administers these programs on nonfederal lands, provides technical assistance, and contracts for needed installations. The Forest Service is responsible for installations and land treatment measures on National Forest System lands and on adjacent lands administered by the Forest Service, and for forestry practices on lands of all ownerships.

Section 102 of the Food and Agriculture Act of 1962[30] provided for assistance from U.S. Department of Agriculture Agencies to Resource Conservation and Development Areas that are organized and sponsored by units of state and local governments. Local program sponsors direct a continuing planning process and install planned conservation measures. The Soil Conservation Service, the Forest Service and other U.S. Department of Agriculture agencies provide technical, financial or loan assistance to local sponsors under the leadership of the Soil Conservation Service.

The technical assistance includes such activities as compilation of soils information, market analyses, wood utilization studies, planning and construction of flood prevention structures and water-based recreation facilities, and identification of sources of public assistance for local area development. The Farmers Home Administration also provides loan services to local program sponsors in connection with planned activities. Other assistance has been provided in selected program areas through arrangements with State Cooperative Extension Services and the Economic Research, Statistics, and Cooperative Services.

The Clean Water Act of 1977[31] authorized the Secretary of Agriculture, with the concurrence of the Environmental Protection Agency, to establish and administer a program of long-term contracts with rural landowners and operators to install and maintain measures incorporating "best management" practices to control nonpoint source pollution for improved water quality. States or areas having an approved Section 208 plan under the Federal Water Pollution Control Act Amendments of 1972[32] may qualify for technical and cost-sharing assistance in carrying out conservation practices on farm, ranch, or other land. This program applies to "rural lands," which are defined as privately owned agricultural lands, including cropland, pastureland, forest land, rangeland, and other associated lands for which the Soil Conservation Service has responsibility.

Extension Service.—The Extension Service of the U.S. Department of Agriculture, in cooperation with State Extension Services, has the lead role in the "education" component of forest technology transfer, with group audiences as the primary clientele. Service to individual landowners and users also may be provided to meet demonstration or similar opportunities.

Agricultural extension activities were initially established under the Smith-Lever Act of 1914,[21] which authorized the Secretary of Agriculture, through the land grant colleges, to provide instruction and practical demonstrations in agriculture and related subjects. The Rural Development Act of 1972,[33] the Farmer to Consumer Direct Marketing Act of 1976,[34] and the Food and Agriculture Act of 1977[14] also provided authorizations for extension programs. In 1978 the Renewable Resources Extension Act[35] specifically authorized education programs for private forest and range landowners, wood processors, and users of forest and range renewable resources.

The Extension Service furnishes program leadership and assistance to state and county extension services, and administers a program of federal grants to the states for agricultural and forestry extension.

Extension programs provide landowners and resource users with information on technology for protecting and managing forests and rangelands and for timber, livestock, recreation, or other goods and services. Assistance in urban forestry is made available to officials and others involved in forestry work and tree problems. Information also is provided to the general public regarding the importance of forest and rangeland resources for production of economic and environmental benefits.

Agricultural Stabilization and Conservation Service.—The Agricultural Stabilization and Conservation Service is involved in forest and range programs primarily through administration of cost-sharing activities provided through the Agricultural Conservation Program, the Forestry Incentives Program and the Conservation Reserve Program. These forestry programs are conducted in coordination with the technical assistance and education activities of other U.S. Department of Agriculture and state forestry agencies. The Agricultural Stabilization and Conservation Service may provide technical information to landowners who, or may refer them to the appropriate technical agencies.

Under the Soil Conservation and Domestic Allotment Act of 1936,[28] federal funds have been appropriated to

provide cost-sharing to farmers for a variety of conservation and land treatment measures. This Agricultural Conservation Program is administered by the agency through a system of state and county committees. A limited part of the funds available in this program has been assigned for forestry practices such as tree planting, stand improvement, wildlife habitat improvement, and fencing against livestock. The Forest Service and state forestry agencies provide advice and assistance in developing programs and in monitoring cost-sharing contracts with participating forest owners.

The Forestry Incentives Program is specifically designed for federal sharing of the costs of forestry practices with nonindustrial private landowners. The program was authorized in the Agricultural and Consumer Protection Act of 1973[36] and subsequently in the Cooperative Forestry Assistance Act of 1978.[25] The purpose of this program is to encourage improved forest management for production of timber along with associated forest commodities and uses. The Agricultural Stabilization and Conservation Service has administrative responsibility for this program and handles eligibility, waiver procedures, and payments to participants. The Forest Service provides technical input, such as specifications for forestry practices and recommendations on apportionments of available funds. State forestry agencies and cooperating private foresters and consultants provide technical assistance to landowners, in helping develop individual forest management plans and inspecting installed practices to ensure compliance with guidelines and contracts.

The Forestry Incentives Program involves both short- and long-term cost-sharing agreements with private landowners to plant trees or otherwise improve stands of forest trees by thinning, pruning of crop trees, prescribed burning, or release of desirable seedlings and young trees on sites suitable for production of products such as sawlogs and veneer logs. Cost-sharing can be provided for up to 75% of the costs of tree planting and other stand improvement measures, depending on the cost-share rate set by the Agricultural Stabilization and Conservation Service in consultation with a committee of state foresters or equivalent state officials. Eligible landowners must own 1,000 acres or less, or up to 5,000 acres if significant public benefits can be expected.

The Forest Service also cooperates with the Agricultural Stabilization and Conservation Service by providing technical assistance for the Conservation Reserve Program. The Food Security Act of 1985[37] established the Conservation Reserve to remove highly erodible cropland from agricultural production. Participants receive annual rental payments for 10 years to keep land out of production. They also receive up to 50% of the cost of establishing permanent cover on these lands. Under the legislation establishing the Conservation Reserve, Congress established a goal of 12.5% for tree planting out of a total goal of 40 to 45 million acres of land in the Reserve. Tree planting under this program is proving to be the largest single tree-planting program in the United States.

Farmers Home Administration and Land Banks.— The loan program of the Farmers Home Administration provides for limited loans to farmers unable to obtain reasonable credit elsewhere including:

- soil and water loans to farmers, associations, and others for resource development, including improvement of forest resources;
- operating loans to farmers, including loans for harvesting and processing timber products;
- grazing loans, generally made to associations of three or more ranchers for the purchase of grazing land; and
- recreational loans to farmers for converting portions of farms or ranches to income-producing recreation enterprises.

Loans from the Federal Land Banks also include credit to landowners offering forest resources as collateral. Such loans have steadily grown in importance, particularly in the southern states and the Pacific Northwest.

Other federal and state Agencies also conduct programs relating to management and use of private forest and range lands:

- The Fish and Wildlife Service in the Department of the Interior provides financial and technical assistance to states for the restoration and improvement of habitat for fish and wildlife, including forest and range habitats.
- The Environmental Protection Agency and related state agencies administer programs for water and air quality that include specifications for "best management practices" that forest owners and operators must follow in silvicultural and related activities. The Agency also is responsible for the registration and certification of the use of pesticides, including those widely used in forestry.

Relationships with the General Public

A variety of federal and state programs are thus in operation to inform and help private owners and operators of forest and range land in the management and development of forests, ranges, and related resources

and in the operation of forest-based industries. Most of the technical assistance, extension education, and cost-sharing programs of the U.S. Department of Agriculture agencies and state forestry and extension agencies are directed toward nonindustrial private forest ownerships held by farmers and other miscellaneous owners. These technical assistance and technology transfer programs also benefit large numbers of small timber businesses.

Transfer of knowledge and technology is one of the important responsibilities of Cooperative Forestry. This is carried out in a wide variety of ways including training, symposiums, preparation and distribution of publication and consultations.

Part of the involvement of Cooperative Forestry is in areas where urban growth is taking place in wildland areas. Here information on forest management, forest health and fire protection is provided. Cooperative programs are also concerned with improving the quality of life in urban areas by providing assistance for planting and management of trees, shrubs, and other vegetation.

NATIONAL FOREST SYSTEM PROGRAMS

The National Forest System lands includes some 191 million acres of federal land, or about 13% of the total forest and range lands in the Nation. These lands are located in 43 states, Puerto Rico, and the Virgin Islands. They include 156 national forests, containing 186 million acres and 19 national grasslands, containing 4 million acres. The remaining acreage is in land utilization projects, research and experimental areas, and other areas.

The national forest lands comprise some 160 million acres reserved from the public domain under the Creative Act of 1891,[38] plus 23 million acres of lands acquired by purchase, donation, or exchange under the Weeks Law of 1911,[25] the Clarke-McNary Act of 1924,[2] and related legislation.

The land in the National Forest System made up of national grasslands and land utilization projects represents areas of "submarginal" land acquired by the Federal Government under the Bankhead-Jones Farm Tenant Act of 1937[42] for purpose of resettlement and land conservation. These lands are managed by the Forest Service with conservation and demonstration objectives and multiple-use and sustained yield policies similar to those applicable to national forest lands.

The societal justification for public ownership and management of the National Forest System lands is much the same as that for public cooperative and research programs. For timber, water, wildlife and fish and most other renewable resources products of forests and rangelands, the market system for producing goods and services does not work very well. This reflects institutional and societal forces that are very difficult to change or manage.

Here and in many other countries, wildlife and fish are considered public property. This is largely because of the mobile nature of most species of wildlife and fish—it is difficult or impossible to control movement across property and jurisdictional lines. As a result of such characteristics, there is no price in a market sense on most wildlife and fish.

Water at its source in a stream or lake or underground is a free good—costs and prices develop as it is transferred from its point of origin or stored for future use. Many forms of outdoor recreation are also free or available at prices below the providing cost.

The lack of market prices is partly due to the mobile nature and public ownership of the resource. It also results from the broad societal nature of the benefits. For example, there seems to be no practical way to establish a market price for scenic beauty, water quality, songbirds, or the enjoyment associated with nature walks.

Some products of forest and range lands, especially timber and forage, do have established markets and prices. But the problem with these goods, particularly timber, is the limited response to price changes. In the case of timber, for example, for each 10% increases in price there is less than a 4% increase in supplies.

Because of the problems associated with supplying the desired quantities of most of the resources of forest and range, society has taken action to supplement market forces. The establishment and maintenance of the National Forest System, nearly all forestry legislation, as well as the public programs of protection, technical and financial assistance, research, and education are all societal adjustments designed to supplement the market system, serving to increase and protect national supplies of timber, water, wildlife and fish, and many forms of outdoor recreation.

Authorization for the National Forest System

Forests have been a matter of public concern since settlement began and has intensified with time. After the Civil War, forests were being cut at very rapid rates. Part of the cutover lands were used for crops and pasture. Because of such use and due to uncontrolled fires which burned each year, only a part of cutover land came back to forests. Floods and erosion were becoming serious problems over large areas and timber supplies were becoming economically scarcer.

In the 1870's and 1880's there were a series of studies, articles, and other material describing the situation, including the comprehensive 1878 "Report upon Forestry" by Franklin B. Hough.[39] New organizations, in-

cluding the American Forestry Association, were formed and began to build support for action. Influential members of the Federal Government and other concerned groups actively promoted the idea of "forest reservations" to protect part of the remaining forested public lands. As a result of these efforts Congress, in the Creative Act of 1891,[38] authorized setting aside public lands as timber reserves. This was followed by the Organic Administration Act of 1897.[40] This Organic Act remained essentially unchanged until the passage of the Multiple-Use Sustained Yield Act of 1960.[41] The National Forest Management Act of 1976[2] established additional Congressional standards and guidelines for the National Forest System. It also added specific direction for public participation in National Forest System planning and management.

The setting aside of public lands was supplemented in 1911 by the Weeks Law[20] which for the first time authorized the purchase of private lands in the headwaters of navigable streams in the eastern United States for inclusion in the National Forest System. The Clarke-McNary Act of 1924[7] provided broader authorization for the purchase of private lands for the National Forest System. Some lands purchased under the Bankhead-Jones Farm Tenant Act of 1937[42] were also in time transferred to the National Forest System.

Scope and Goals of the National Forest System

The goals of the National Forest System as defined in the Organic Administration Act of 1897[40] were to "improve and protect the forest within the reservation, or for the purpose of securing favorable conditions of waterflows, and to finish a continuous supply of timber for the use and necessities of the United States." From the beginning the National Forest System lands were managed not only to provide timber and watershed protection but other economic and social benefits: grazing, wildlife and fish, outdoor recreation, minerals and many other goods and services. Although the Organic Act, the Weeks Law and appropriation acts made clear in general ways that this was the will of Congress, the policy was not brought together formally until the Multiple-Use Sustained Yield Act of 1960.[41]

This act states:

> It is the policy of the Congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes....The Secretary of Agriculture is authorized and directed to develop and administer the renewable surface resources of the National Forests for multiple use and sustained yield of the several products and services obtained therefrom....

The National Forest Management Act of 1976[2] established additional Congressional standards and guidelines for the administration of the National Forest System, including directives for comprehensive multiple-use resource planning.

Under this Act, the Forest Service is developing long-range integrated management plans for each national forest. This involves use of interdisciplinary planning teams and continuing public participation. A committee of scientists made up of representatives of the various disciplines which bear on land management planning has also furnished scientific and technical advice in drafting regulations that prescribe standards and guidelines for resource planning.

Part of the National Forest System land is managed for designated purposes. The most important areas in size of this kind are those designated as wilderness.

The first area of wilderness in the United States was established in 1924 by administrative order of the Forest Service on the Gila National Forest in New Mexico. By the time Congress enacted the Wilderness Act of 1964,[43] some 9.1 million acres of wildland areas in the National Forests had been designated under U.S. Department of Agriculture regulations as wilderness, wild or canoe areas, and some 5.4 million acres as primitive areas. The Wilderness Act of 1964 established a National Wilderness Preservation System:

> ...to be composed of Federally owned lands designated by Congress as "wilderness areas"...administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness...wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use.

The Eastern Wilderness Act of 1975[44] added certain areas in eastern National Forests to the National Wilderness Preservation System and designated additional wilderness study areas for review of wilderness potentials. Other acts of Congress, including the Endangered Wilderness Act of 1978,[45] also made additions to the wilderness system in the national forests. Small areas of National Forest System Lands are also designated as administrative sites, experimental areas, wild and scenic rivers, campgrounds, and other limited uses.

Program Areas

At any given time within the existing framework of legislation and goals, National Forest System programs are largely determined by appropriations. These appropriations reflect the current priorities of the Administra-

tion and of Congress and provide a means of changing the National Forest System programs in accord with consensus views of the time. Thus, the way the National Forest System lands are used and managed reflects, as well as a democratic system can, the desires and expectations of the people.

The fiscal year 1988 appropriations for National Forest System programs are shown in table 3. The appropriations have been grouped for budgetary and administrative purposes into major resource and management categories shown in the table. All the resource and management activities are interrelated, however, and require integration through multiple-use planning and balanced management of often conflicting uses.

Mineral Resource Management

National Forest System lands are of major and increasing importance for production of a variety of metals and other minerals. These lands contain an estimated 50 billion tons of coal. These lands have potential for oil, gas, geothermal, uranium, phosphate, lead, gold, silver, sand and gravel, and many other minerals.

Part of the Forest Service minerals program involves evaluating applications or proposals of industry to explore and develop energy and mineral resource on National Forest System lands. This is done in cooperation with the Bureau of Land Management, the Bureau of Mines, the Office of Surface Mining Reclamation and Enforcement, and the Geological Survey in the U.S. Department of the Interior. The Forest Service and the Bureau of Land Management also cooperate in the preparation of documents required by the National Environmental Policy Act of 1969.[46]

The Forest Service develops procedures and requirements for mineral activities in coordination with other resource values and uses. The Forest Service's minerals program also involves the authorization and administration of ancillary projects such as roads and pipelines that are part of mineral development projects. Furthermore, where privately-owned minerals underlie the federal surface, the Forest Service manages surface activities associated with the exploration and development of the private mineral estate.

Federal mineral and energy resources are categorized as leasable, locatable, and mineral materials. The Forest Service has programs for each.

Leasable minerals.—Under the Mineral Leasing Act of 1920[47] the Secretary of the Interior, through the Bureau of Land Management, is authorized to issue permits or leases, for prospecting and development of "leasable" minerals on public lands, including National Forest System lands reserved from the public domain or acquired by certain land exchanges where "public land"

Table 3.—Forest Service funds, for National Forest System programs, fiscal year 1988.

Program	Funds (thousand dollars)
Appropriated Funds:	
Minerals Area Management	26,683
Real Estate Management	21,834
Land Line Location	26,651
Maintenance of Facilities	16,533
Forest Fire Protection:	
Fire presuppression	156,477
Fuels management	8,552
Subtotal	165,029
Fighting Forest Fires	125,000
Cooperative Law Enforcement	9,669
Forest Road Maintenance	83,740
Forest Trail Maintenance	20,026
Timber Sales Administration and Management:	
Sales preparation	98,432
Harvest administration	44,333
Timber resources inventory planning	16,177
Silvicultural examination	26,619
Subtotal	185,561
Reforestation and Stand Improvement	54,923
Recreation Use:	
Recreation management	96,945
Wilderness management	12,581
Cultural resource management	14,216
Subtotal	123,742
Wildlife and Fish Habitat Management:	
Wildlife habitat	5,634
Inland fish habitat	3,846
Anadromous fish habitat	4,123
Endangered, threatened, and sensitive species habitat	4,489
Administration and resources coordination	29,352
Subtotal	47,444
Range Management	29,225
Soil, Water and Air Management	35,271
General Administration	268,660
Construction:	
Construction of facilities	24,735
Forest road construction	171,764
Trail construction	14,671
Subtotal	111,170
Land acquisition	49,076
Total Appropriated	1,500,237
Permanent Appropriations-Working Funds:	
Brush Disposal	54,438
Timber Roads, Purchaser Elections	4,551
Timber Salvage Sales	61,502
Tongass Timber Supply Fund	50,007
Operation and Maintenance of Forest Service Quarters	5,500
Other	200
Total Permanent Appropriations	176,194
Trust Funds:	
Knutson-Vandenburg (K-V) Reforestation	114,123
Timber Stand Improvement	31,131
Other	55,453
Cooperative Work (Other)	58,332
Reforestation Trust Funds	30,000
Total Trust Funds	289,039
Total National Forest System	1,965,470

or timber thereon was granted in exchange. These minerals include coal, oil, oil shale, native gas, phosphate, sodium, asphalt, bitumen and bituminous rock, potassium, and sulphur.

The Mineral Leasing Act for Acquired Lands of 1947[48] grants similar authority to the Bureau of Land Management to lease deposits of "leasable" minerals on acquired lands in the National Forest System. Regulation of surface coal mining operations and rehabilitation of mined areas by the Department of the Interior also are provided for in the Surface Mining Control and Reclamation Act of 1977.[49] The Geothermal Steam Act of 1970[50] similarly requires that geothermal leases on National Forest System lands are subject to the consent and conditions of the Secretary of Agriculture to protect lands for purposes for which they were withdrawn, or acquired.

In accord with the legislative direction, the Forest Service Leasable Minerals Program involves:

- Acting on leasing applications and related proposals and forwarding recommendations/consents to the Bureau of Land Management with stipulations to improve coordination with surface resources.

- Determining terms and conditions to be included in plans of operation to be approved by Forest Service or by Bureau of Land Management.

- Ensuring that mineral exploration, development, production, and reclamation activities comply with applicable laws and regulations.

- Ensuring coordination with surface resources and other land uses.

- Monitoring activities for compliance with an approved plan of operation, prospecting permit, and exploration license requirements.

- Issuing and administering special use permits associated with leasable minerals.

Locatable mineral.—Most national forest public domain lands are open to location of mining claims under the Mining Law of 1872.[51] Mining claims may be located by citizens for all minerals which are not subject to disposal under the leasing laws or the Minerals Materials Act. Included in these "locatable minerals" are such minerals as gold, silver, copper, lead, and zinc. Locatable mineral operations such as exploration or production are subject to the Forest Service locatable minerals regulations which require operators to obtain Forest Service approval of their plans of operation. On mining claims located after July 23, 1955, and before patent, the Forest Service may manage and dispose of vegetative resources under provisions of the Multiple Use Mining Act of 1955.[52]

The Forest Service locatable minerals program involves:

- Ensuring compliance with the U.S. Mining Law of 1872 and applicable regulations.

- Ensuring coordination with surface resources and other land uses.

- Processing plans of operation.

- Monitoring mining activities for compliance with requirements in approved plans of operation.

- Examining the validity of mining claims.

Mineral material.—The Secretary of Agriculture has the authority to dispose of mineral materials from National Forest System lands. Mineral materials include, but are not limited to most occurrences of sand, stone, gravel, pumice, pumicite, cinders, and clay. The Secretary's authority to dispose of these materials stem collectively from the Materials Common Varieties of Mineral Act of July 1947[53] and the Transfer Act of June 11, 1960[54] and other special acts. Mineral materials are sold outright, granted free of charge to qualified users, or used to build and maintain Forest Service road systems and other facilities.

The Forest Service Mineral Materials Program involves:

- Complying with laws and regulations.
- Administering sale and free-use disposals.
- Inventorying the mineral materials resource.
- Conducting appraisals.
- Developing and implementing forest-wide Mineral Material Management Plans and site development plans.
- Ensuring coordination with surface resources and other land uses.
- Monitoring operations, including reclamation applicable to all disturbing activities.

Geology.—Besides mineral resource management, the Forest Service has the responsibility to provide and interpret geologic and minerals resource information for land management planning, environmental protection, mined-land reclamation, and other agency or state cooperative management programs. More specifically the geology program:

- Provides geologic support personnel to gather, interpret, and present information about geologic conditions and mineral resources for resource evaluation and land management planning.
- Gathers, interprets, and reports geologic factors that affect the design, construction, and maintenance of Forest Service facilities.
- Gathers and interprets geologic information needed to develop and protect such resources as ground water, underground spaces, and minerals.

Real Estate Management

The Real Estate Management Program of the Forest Service is concerned with land exchange and adjustment, land classification and status, title claims, landownerships planning, special land uses, and mapping.

Land exchange.—The Land Exchange Program involves exchange of land between the National Forest System and other ownerships under authority of the General Exchange Act of 1922,[55] the Weeks Law of 1911,[20] and several special acts. The objectives of the Land Exchange Program are to consolidate ownerships, improve administration of the properties involved, reduce the costs of protection and administration, and resolve claims and trespass problems. In the western states, many land exchanges involving large acreages have been transacted with state and local governments, railroads, timber and mining companies and ranchers. The properties often involve "checkerboard" landownership patterns resulting from 100-year-old land grants. Exchanges are a means of solving problems caused by fragmented ownership. Many exchanges help local communities by exchanging isolated tracts of nonfederal land for federal land adjacent to expanding communities. Recent wilderness acts include provisions directing acquisitions of nonfederal land by exchange to preserve the wilderness character.

Land classification and status.—The program, concerned with classification and status, aims to record the land area, location, and interests in the National Forest System lands in order to improve protection, management, and development of resources. Additionally, it seeks to ensure proper administration of lands subject to reservations, outstanding rights, mineral withdrawals, other conditions of title and laws that direct or affect land management. Further concerns of the program involve resolution of land title claims and planning for landownerships adjustments.

Special land uses (nonrecreational).—This program is directed at authorizing and monitoring the use of National Forest System lands by federal, state, and local agencies, by private industry including utilities, and by individuals for a wide variety of special purposes. These include rights-of-way for power, oil and gas lines; microwave towers and other communication facilities; and water power developments. Most users are charged a fee based on the fair market value of the use.

A major part of the program is concerned with the processing of hydroelectric development proposals. The Forest Service is responsible for developing terms and conditions for protecting National Forest System lands which must be included in licenses granted by the Federal Energy Regulatory Commission. Some special uses, such as hydroelectric facilities, can result in significant changes in the management and use of an area. To help assess these changes, the Forest Service completes a detailed review of the proposal, alternatives to the proposal, and the impacts of the proposal on the environment. Authorizations are not granted until the review process is completed and the Forest Service is satisfied that the environmental impacts associated with the use can be mitigated and it is within the Forest's management guidelines.

Mapping (geometronics).—This program involves National Forest System lands, showing the terrain, developments, and the composition and extent of vegetation or other resources. Primary base maps for 7½-minute quadrangles are prepared and revised periodically in cooperation with the U.S. Geological Survey. Secondary base maps covering complete national forests are prepared by the Forest Service for administrative and forest visitor uses. Project maps and special purpose maps are produced for use in the design of developments such as roads, recreation areas, timber sale layouts, and logging plans.

Land Line Location

The land line location program is concerned with locating, marking, posting and maintaining property lines between National Forest System lands and other property. Sometimes, where the costs of land location surveys exceed the purchase costs of in-holding tracts, the Forest Service can purchase such in-holdings from willing sellers using land line program funds. Some land surveys are made by the Bureau of Land Management on a reimbursable basis.

Maintenance Of Facilities

The Forest Service has over 11,000 permanent buildings used for fire and administrative purposes, for service and general storage, and for associated utility

systems. These facilities are located primarily at ranger district and work center locations. Nearly half of these facilities were constructed before 1940 and more than four-fifths before 1965. Owing to the fact that the structural and functional life expectancy of these buildings range from 30 to 35 years, deferred maintenance and increased service demands have resulted in an extensive maintenance backlog. About 40% of the appropriated funds relate to health and safety items.

The Maintenance of Facilities portion of the National Forest System program is directed toward repairing, renovating and maintaining these facilities to meet growing needs for use.

Forest Fire Protection

The Forest Fire Protection Program protects life, property, and natural resources on the 191 million acres of National Forest System lands. Additional acreage is protected on adjacent state and private lands, protected through fee or reciprocal protection agreements. Protection is provided to these lands under the Cooperative Funds Act of June 30, 1914,[56] when it is not economical or practical to provide separate fire protection organizations or when such cooperation is necessary to protect National Forest System resources.

The Forest Service's program is divided into two parts—fire presuppression and fuels management.

Fire presuppression.—Fire presuppression activities provide the Forest Service with the capability to prevent or take effective initial suppression action on wildfires. The Forest Service also helps other federal agencies and states through training programs, planning assistance, joint use equipment contracts, and interagency fire coordination centers.

Presuppression encompasses all activities from discovery to initiating action on fire. It includes activities such as fire planning, training fire fighting personnel, maintenance of fire attack forces and equipment, disposal of logging slash, construction of fuel breaks, equipment development and testing, fire detection, and initial attack on fire starts.

Presuppression also includes restriction on access in times of critical fire danger, and limitations on use of fires and logging or other equipment. Law enforcement activities for Forest Service personnel, distribution of educational literature on forest fires, and personal contacts with National Forest System users also aid in the prevention of fires.

Specialized tasks are performed using airplanes and helicopters. They are used to locate and map fires both ocularly and with infrared sensors, for transporting cargo and personnel, for directing fire operation, and for the application of fire retardant.

Fuels management.—Fire occurrence, fire behavior, damage from fire and fire suppression costs often can be significantly influenced by managing natural fuels. The fuels management program includes support and planning for fuels activities, inventory of fuel hazards, analysis of alternatives for treating these hazards, and treatments. Treatment includes yarding and stockpiling woody materials for increased utilization, hand or mechanically manipulating fuels to a less flammable and obstructing condition, and reducing fuel volume by removal or prescribed fire.

Fighting Forest Fires

The fire fighting program is directed toward fighting wildfires on or threatening National Forest System lands, and to rehabilitating burned over National Forest System lands. It is also used to supplement presuppression activities when above-average forecasted or actual burning conditions exceed a nationally determined acceptable level of risk.

The suppression of wildfires burning on or threatening National Forest System lands is a major and hazardous program that varies in size from year to year. Fires are suppressed by ground and air attack. Ground attack includes hand crews, pumpers, and other mechanized equipment. Air attack includes smokejumpers, helicopters, air tankers and other specialized aircraft for detection, surveillance and transportation. Because of the variability in fire conditions and firefighting costs from year to year, suppression costs above the appropriated level are provided for by supplemental appropriations.

Cooperative Law Enforcement

Law enforcement programs are directed at protecting natural resources, federal property, employees and visitors on the National Forest System lands. Some major law enforcement investigative activities include wildland arson, timber theft, cannabis detection and eradication, internal investigations, theft, and destruction of archeological resources.

The cooperative law enforcement program provides funding to local law enforcement agencies for protection of visitors and their property on National Forest System lands. Authority for such cooperation was included in the Cooperative Law Enforcement Act of 1971,[57] which provided for federal reimbursement of local governmental expenditures incurred in connection with the enforcement of state laws and local regulations on National Forest System lands.

Most funds made available in this program are expended for patrol activities, or services such as station-

ing law enforcement officers in problem areas. This funding is also used to reimburse state and local law enforcement agencies for extraordinary expenses associated with protecting the public and their property on the national forests. Often, the number of visitors to the National Forest System lands equal or greatly exceeds the resident population of the counties. Since this visitor use is seasonal and often occurs in geographically remote areas, this funding helps these small local law enforcement agencies provide protection for the public on National Forest System lands.

There is also a cooperative program for reimbursements to local law enforcement agencies for the detection, investigation, and eradication of cannabis on National Forest System lands. These agreements are executed separately from regular cooperative agreements. The major concern of these agreements is protecting National Forest System resources, operations, employees and forest visitors from danger associated with illegal cultivation, manufacture, or distribution of cannabis or other controlled substances on National Forest System lands. There is a risk to national forest visitors, contractors, and employees when they encounter those who are tending or guarding these lucrative crops. Reducing the use of the national forests for cannabis production is essential to maintain a safe environment for all users of the National Forest System.

The Drug Abuse Act of 1968[58] provides for the detection of cannabis being cultivated within the boundaries of the National Forest System and also provides for the apprehension and prosecution of persons involved in cultivation. Funding for this program is expended internally within the Forest Service and is not for disbursement to state and local law enforcement agencies.

Forest Road Maintenance

At the beginning of FY 1989 the forest development road system on National Forest System lands contained about 353,900 miles of various standards and types of road. Approximately 17% of the system is maintained in a closed condition, approximately 52% of the system is maintained for use only by high clearance vehicles, with the remaining 31% of the system being maintained for use by standard passenger cars. The road maintenance program provides essential access for using and managing lands. Specific work activities include roadside brushing, surface grading, culvert cleaning, repairing bridges, replacing depleted surfacing materials, and replacing damaged or nonfunctioning traffic control devices. It also includes transportation system management activities such as traffic studies, regulating and controlling traffic, determining and resolving jurisdiction problems, managing construction and enforcing applicable regulations.

Federal appropriations provide for approximately 48% of the funding for this program. Purchasers of government timber are responsible for another 48%. Other commercial users, such as those in mining or hauling private timber, are responsible for the remaining 4%.

The Forest Service is responsible for all maintenance attributed to administrative and noncommercial use. Most traffic on the forest development road system is by the general public, primarily for recreation. The Forest Road Maintenance program funds all the maintenance for which the Forest Service is responsible.

Much required road maintenance work does not result from road use. This work includes cleaning culverts, clearing roadside brush, removing landslides, maintaining traffic control devices, and painting bridges. These maintenance costs are shared by the Forest Service and the commercial users when the roads are used for commercial hauling. The Forest Service assumes responsibility for all these costs when the roads are not in commercial use.

Forest Trail Maintenance

The National Forest System contains about 105,000 miles of trails ranging from primitive pathways through wilderness areas to paved walkways. The purpose of the Forest Service trail program is to manage, operate and maintain this system to provide opportunities for recreational and administrative travel.

Trail maintenance includes clearing pathways of encroaching vegetation and fallen trees, and repairing or improving of trail signs, treadways, drainage facilities, and bridges. Trail maintenance is popular with volunteers and is often a share-cost program. The Forest Service provides equipment, food, supervision, training, and some transportation; volunteers give labor and organization.

In general forest areas, modern equipment and transportation are used to clear and maintain the trails. In contrast, primitive tools and techniques are used in wilderness areas to minimize the impact of human influence on these wildlands. In these areas, trail workers use hand saws or axes to clear fallen trees from the path and pack animals to carry equipment and food.

Timber Sales Administration and Management

Timber harvesting is a major use on nearly 90 million acres of National Forest System lands—about half the total area of the national forests. Timber harvests, averaging more than 10 billion board feet annually, provide approximately one-fifth of the Nation's total production

of lumber and other wood products. The timber resources on these federal lands are thus of major importance to many rural communities supported by logging and milling operations, and to other industries and consumers of housing, paper products, and other wood-based materials.

The basic purpose of the timber management program on the National Forest System lands is to produce continuous flows of timber harvests in perpetuity, while protecting environmental values and other land uses.

The program is divided into four parts: sales preparation, harvest administration, timber resource inventory planning, and silvicultural examination.

Sales preparation.—The first step in harvesting timber from the national forests is sales preparation. The preparation of timber sales includes the location and marking of timber in stands considered ready for harvesting under approved multiple-use and timber management plans, together with the drafting of contract requirements for timber harvesting, road construction, and related activities. The advertisement of sales and awarding of sales to successful bidders follow. In the layout of timber sales and in planning for timber harvesting, professionals in landscape management and design, wildlife management, and other disciplines cooperate to ensure that logging operations will be conducted in ways that will maintain the ecological and environmental quality of the lands involved.

Authorization for sale of timber on National Forest System lands "at not less than appraised prices" was initially authorized in the Organic Administration Act of 1897.[40] The National Forest Management Act of 1976[2] added specific requirements for timber sale and harvesting programs, including guidelines for cutting methods and limitations on volumes of allowable harvests and bidding practices. Further authority for alternative methods of timber sales was included in the Timber Sales Bidding Act of 1978.[59]

Provisions for a "set aside" of certain timber sales for small business concerns, in a program jointly developed with the Small Business Administration, were included in the Small Business Act of 1958.[60] Joint studies also have been conducted with the Bureau of Land Management and the Bureau of Indian Affairs to coördinate federal timber sale procedures.

Harvest administration.—The Harvest Administration Program is directed at administrating wood harvesting on National Forest System lands in accordance with timber sale contracts and permits in order to minimize adverse environmental impacts, maximize benefits, and protect the government from fraud, abuse and waste.

Timber sale contracts are administered to meet land management objectives, fulfill contractual obligations, and protect the public's interests. Administration includes ensuring that purchasers understand objectives, monitoring their activities for contract compliance, approving their work, measuring (scaling) their logs for payments, ensuring proper log accountability from stump to mill, ensuring that contract payments are adequate for the expected level of activity, negotiating and resolving disputes about contract performances, and enforcing laws applicable to the purchasers' operations and contracts.

Timber resource inventory planning.—The Inventory Planning Program and the Silvicultural Examination Program described below develop information necessary for planning the orderly management of national forest timber resources. This information is used primarily to determine lands suitable for timber production, determine allowable sale quantities, establish timber-sales schedules, and identify opportunities for intensive forest management. The inventory data is also used in the management of wildlife, recreation, and other resources.

Timber resource inventories conducted in this program provide information needed for land classification, determining timber volumes, and monitoring growth rates. Other information is also gathered for forest land and resource management plans. These inventories describe the conditions and extent of the timber resource on each national forest, providing a measure to evaluate changes during the planning period.

Inventories also provide resource information for research publications and the National Assessment Program required by the Forest and Rangeland Renewable Resources Planning Act.[1] With the completion of a major part of the land management planning effort, about 16 million acres will be inventoried annually under this program. This schedule will help meet the requirements for a 10-year review cycle of National Forest System land and resource management planning.

This cycle of timber resource inventories is coordinated with the schedule for state forest inventories carried out under the Forest Research appropriation for forest inventory and analysis.

Silvicultural examination.—The Silvicultural Program provides periodic review and analysis of timber conditions and treatment needs to meet forest and resource management plan objectives. It also provides information for monitoring and certifying silvicultural treatments to ensure that timber resources are managed properly.

This program gathers timber stand data, compiles and stores these data in stand files, and prepares an analysis and written prescription for about 5 million acres of forest land annually to ensure proper treatment. This program and the timber inventory planning program provide information needed for planning the orderly management of national forest timber resources.

Timber stands are normally examined at 10-year intervals so that land managers can monitor changing stand conditions and treatment needs.

Reforestation and Stand Improvement

The Reforestation and Stand Improvement Program is directed toward obtaining adequate stocking of forest lands and maintaining a level of timber productivity sufficient for sustained yield management of National Forest System lands. The program aims to increase the growth rate and product quality of timber growing on national forests to levels consistent with environmental quality, multiple resource use objectives, and social and economic benefits and costs.

The Reforestation and Stand Improvement Program is financed with appropriated funds, Reforestation Trust funds, and Knutson-Vandenberg funds (K-V) (table 3). The appropriated funds are used to reforest harvested ares; areas damaged by fire; insects, or disease, by unsuccessful plantations; and to release planted trees, competing vegetation, or overcrowding.

The appropriated funds pay for seedlings purchased from Forest Service and private nurseries. Contracts for site preparation, animal damage control, fertilization, tree planting, release, precommercial thinning, and a limited amount of tree pruning are also charged to these funds.

The Knutson-Vanderberg funds in the Trust Funds appropriation are used to purchase seedlings for reforesting timber sale areas. Seedlings to be planted on all other areas, such as areas burned by wildfires, are purchased with funds from the National Forest System appropriation.

The Forest Service is also authorized under the Act of March 3, 1925[61] to cooperate with owners of nonfederal lands situated within or near national forests and to accept deposits for reforestation or other work on such lands. These holdings are usually too small to warrant employment of professional foresters. Cooperation with the Forest Service in such instances benefits the Government by reducing possible fire hazard or other adverse impacts from improper land use.

The objective of the timber stand improvement part of the program is to increase timber growth or product quality by thinning, remove excess trees, remove competing vegetation, and fertilize stands at desirable levels.

The purposes of the nursery and tree improvement part of the program are to improve the genetic quality of seed planting stock used on National Forest System lands and to produce high quality planting stock in appropriate numbers and species for timely reforestation.

Recreation Use

The National Forest System is the largest supplier of public outdoor recreation in the Nation, with recreation use amounting to more that 238 million visitor days in 1987. This represented more than two-fifths of all recreation use on federal lands.

The goal of recreation management on National Forest System lands is to provide outdoor recreation opportunities as a major component of the multiple use of the forest, range, and related resources on these federal lands. This objective is accomplished by providing a wide range of recreation uses and facilities, including wilderness, dispersed recreation areas, developed recreation areas, visitor information services, and management of visual resources.

Recreation uses on the national forests were specifically authorized in the Multiple Use Sustained Yield Act of 1960,[41] and on National Grasslands by the Bankhead-Jones Farm Tenant Act of 1937.[42] A long series of appropriation acts included provisions for an expanding program of development of recreation facilities and management of outdoor recreation on the national forests. The National Forest Management Act of 1976[2] also provided authorization and guidelines for inclusion of recreation in multiple-use management. The program has three major parts—recreation management, wilderness management, and cultural resource management.

Recreation management.—The purpose of recreation management is to provide and protect the natural resources and facilities that accommodate the public's need for outdoor recreation, emphasizing opportunities to know and experience nature. It is also directed at maintaining, repairing, and restoring existing facilities necessary to meet the demands for public outdoor recreation in natural settings. Private sector capital through concession permits, challenge cost-share projects, and other partnerships are used when appropriate.

Wilderness management.—Wilderness management is directed at protecting and preserving resources and values while providing for the uses permitted by law. Wilderness is managed for scenic, scientific, educational, conservation, historical, and recreation use. Although people enjoy visiting wildernesses and experiencing the primitive environment, these lands are not primarily recreational areas. About 5% of recreation use on the national forests occurs in designated wilderness areas.

The Forest Service manages 348 wilderness areas in 35 states with a total of 32.4 million acres. One acre in six of the National Forest System is now in the National Wilderness Preservation System.

Cultural resource management.—The purpose of the cultural resource program is to protect, manage and

interpret the cultural resources on National Forest System lands in accord with the requirements of the National Historic Preservation Act of 1980[62] the National Environmental Policy Act of 1969[18] and the Archaeological Resources Protection Act of 1969.[63] The program also includes field surveys of National Forest System lands to identify cultural resources properties, the preparation of nominations to the National Register of Historic Places, and the enforcement of laws protecting cultural resources.

The loss of cultural resources to vandalism, pot-hunting, illegal digging, and theft in many parts of the country is a great concern. The Forest Service has been investigating and prosecuting pot-hunting cases since the mid-1970s. Since passage of the Archaeological Resources Protection Act of 1979, Forest Service special agents have been directly involved with many convictions in several States.

Wildlife and Fish Habitat Management

The National Forest System provides most of the habitat for many fish and wildlife species, such as cutthroat trout, moose, black bear, elk, bighorn sheep, and mountain goats. It is also key to the survival and recovery of many threatened or endangered species, such as the grizzly bear, woodland trout, and gray wolf. Habitats for 153 federally listed threatened or endangered species are managed on National Forest System lands.

Wildlife and Fish Habitat Management was initially authorized under general provisions of the Organic Administration Act of 1897[40] and in later appropriation acts. The Multiple-Use and Sustained Yield Act of 1960[41] and the National Forest Management Act of 1976[2] provided specific authorization for management of National Forest System lands for wildlife and fish along with other uses. The Endangered Species Act of 1973[64] has also required the identification of endangered and threatened species of animals and plants and the management of federal lands to ensure perpetuation of these species.

The goal of wildlife and fish management on National Forest System lands is to maintain healthy, self-sustaining populations of all existing native and desired non-native vertebrate species; and to improve the habitat productivity for those species highly desired by the public, such as deer, elk, wild turkey, trout, bass, and salmon.

This goal is primarily accomplished through capital investments, which include activities such as seeding, planting, prescribed burning, and aquatic habitat development. Many activities are conducted in cooperation with state wildlife and fish agencies and individuals, conservation groups, and various local, state, and national agencies. Formal partnerships have been developed with many organizations.

The wildlife and fish management program is divided into five parts:

Wildlife habitat.—The Wildlife Habitat part of the program is directed at maintaining or improving habitat for wildlife species in high demand for consumptive or nonconsumptive purpose.

Emphasis is on improving and mitigating impacts from other management activities. Activities include: prescribed burning to improve spring and winter forage for bighorn sheep, elk, deer, and turkey; water developments for quail, chukars, and mourning doves; access management on existing roads to reduce habitat disturbance for elk, mountain goats, and black bear; placement of nesting structures for wood ducks; and streamside and wetland improvements which provide nesting and feeding areas for waterfowl, wading birds, and furbearers.

Wetland improvements, such as the construction of low-head dams to promote the development of marsh vegetation and the creation of potholes, provide nesting and resting areas for a variety of waterfowl and wetland associated species. Many of these projects are accomplished in partnerships with a variety of individuals, groups, and state and federal agencies. The wetlands improvements are a part of the North American Waterfowl Program.

Inland fish habitat.—The Inland Fish Habitat Program is concerned with maintaining or improving the capability of lakes and streams to sustain resident fish populations. Priority is given to projects that implement the fisheries programs of other federal and state agencies and that restore through enhancement the losses resulting from development activities.

Habitat improvements include: installing artificial spawning reefs and fish shelters to improve lake habitats, creating sheltered pools in streams to increase fish holding capacity, and placing structures in streams to provide fish spawning and rearing habitat.

Anadromous fish habitat.—The purpose of this program is to maintain or improve habitat capability to produce salmon and steelhead for commercial fishing, sport fishing, and subsistence uses.

Projects are conducted to maintain and increase the habitat capability for production of West Coast and Great Lakes salmon and steelhead, and Atlantic salmon in the East. Activities include removing fish barriers, placing stream habitat improvement structures, fertilizing lakes, and creating artificial spawning and rearing facilities.

Endangered threatened, and sensitive species habitat.—The goals of this program are to maintain or improve habitat for recovery of endangered and threat-

ened plants and animals and to sustain viable populations of sensitive plants and animals.

The Forest Service provides habitat protection and management for endangered, threatened, and sensitive species found on National Forest System lands. Recovery plans are the basis of habitat improvements which will provide for an increased level of species recovery.

Administration and resource coordination.—This part of the wildlife and fisheries programs is concerned with administration coordination and the provision of biological expertise in planning activities that affect habitat. Administration of the program includes activities such as cooperating with state and federal agencies and wildlife and fish interest groups, planning habitat goals in coordination with other resource activities, training and continuing education programs for biologists, habitat surveys to document current conditions and to plan habitat improvements, habitat monitoring, and developing wildlife and fisheries habitat planning models.

In the Threatened, Endangered, and Sensitive Species Program, administration activities include inventory, mapping, and technical support for species such as grizzly bear, spotted owl, red cockaded woodpecker, and Kirtland's warbler.

For resource coordination, wildlife and fisheries biologists work with other Forest Service resource managers to design projects or programs, such as vegetative management, timber sales, mineral developments, and livestock grazing. In most instances, resource coordination efforts of Forest Service biologists are designed to protect habitat or minimize costs of other resource management programs.

Intensive external coordination is carried on among Forest Service biologists, state and other federal agency personnel, and the foresters, biologists, and planners in various commercial industries which are located within, or adjacent to, National Forest System lands. The public is involved in these activities through their membership in various conservation groups or individual participation.

Range Management

The broad goals of range management on National Forest System lands are to sustain resource values such as soil productivity and water quality; to protect watersheds, wildlife habitat, threatened and endangered flora and fauna, and ecological diversity; and to promote forage production for domestic livestock, wild horses and burros, and wildlife.

Range Management was authorized by general provisions in the Organic Administration Act of 1897,[40] later appropriation acts, in the Multiple-Use Sustained Yield Act of 1960,[41] and in the National Forest Management Act of 1976.[2] The Bankhead-Jones Farm Tenant Act of 1937[42] provided authorization for management of livestock grazing on the national grasslands and land utilization project areas.

The range program is divided into four parts—vegetation management, forage and structural improvements, wild free-roaming horses and burros, and noxious weed control.

Vegetation management is directed at meeting the planned goals for range vegetation while achieving a proper balance between protection and sustained use. It is also directed at demonstrating range management practices for use on private lands and promoting cooperation in the most effective use of range vegetation on all ownerships.

The Forage and Structural Improvement Program is concerned with providing forage for livestock, wild horses, wild burros, and wildlife and the associated facilities such as fences and water developments.

The Wild Free-roaming Horses and Burros Program is concerned with the management, protection and control of these animals (about 1,900) on National Forest System lands.

The Noxious Weed Program is directed at the control of such weeds and the establishment of beneficial plant cover on National Forest System lands, including the reimbursement of local, county and state weed control authorities for such work as provided in the Carlson-Foley Act of 1968.[65]

Soil, Water And Air Management

The goal of the Soil, Water and Air Management Program is to maintain and improve soil, water and air quality and to secure favorable conditions of streamflow.

The program includes:

- Providing information about soil and water capabilities and limitations for use in resource management and planning.
- Improving soil productivity and water quality to provide for favorable conditions of waterflow.
- Developing soil and water conservation practices for all resource management activities that affect soil and water resources.
- Monitoring soil, water, and air resources to determine whether goals for water and air quality and soil productivity are being met and to provide a basis for identifying more effective management practices.

- Maintaining existing soil and water improvements to ensure their continued effectiveness.

- Conducting soil and water resource inventories to meet identified management needs.

- Identifying and quantifying water requirements to carry out management responsibilities on the National Forest System, and securing and validating water rights to meet these requirements through state procedures.

- Prescribed fire planning.

- Preparing emergency rehabilitation plans for lands damaged by wildfires, floods, or other natural disasters.

- Preparing and implementing soil and water improvement plans for lands in declining watershed condition.

- Protecting the air resource through the review of preconstruction applications for private sector development.

- Providing weather data and meteorological expertise for Forest Service resource management.

- Cooperating with other agencies in soil, water and air resource activities and gathering weather information on, or directly affecting, the National Forest System. This work includes water supply and flood forecasting, surveys of air and water quality, management of public water supplies, and cooperation with the Bureau of Land Management in gathering and sharing weather information.

General Administration

The General Administration Program, financed with National Forest System appropriated funds, consists of managerial and support activities that are not readily identified with specific programs when they are planned. These activities include those concerned with program support such as legislative affairs; program development and budget; resources program and assessment; personnel management; civil rights; computer sciences, communications, and information systems management; procurement and property management; equipment and supplies; management analysis and support; public information and involvement; and common services such as rents and utilities.

As part of engineering support, the Forest Service has a technology development and applications program. This program is akin to the development side of corporate research and development programs. As such, it complements activities carried out by the Forest Service research program. The purpose of this program is to develop or identify promising new technology and to help adopt it in all phases of land management.

Construction

The Forest Service construction program provides for acquiring, restoring, constructing and improving buildings, utility systems, dams, recreation facilities, roads, bridges, trails, and other physical facilities. Land acquisition for administrative sites may be included when it is a part of the total project costs.

The construction program is authorized by general provisions of the Organic Act of 1897,[40] the Granger-Thye Act of 1950,[12] the National Forest Roads and Trails Act of 1964,[66] the National Trails System Act of 1968,[67] the Forest and Rangelands Renewable Resources Planning Act of 1974 as amended,[1] the National Forest Management Act of 1976,[2] the Forest and Rangeland Renewable Resources Research Act of 1978,[9] and other legislation.

The construction program is divided into three components—facilities, roads, and trails.

Construction of facilities.—The facilities program is concerned with constructing, replacing and improving building and related facilities to support forest research, state and private forestry, and National Forest System programs. It includes portable structures (trailers and modular units) that became an integral part of the site. It also includes such facilities as airports; heliports; water, waste, and electrical systems; and recreational facilities.

Forest road construction.—The road construction and reconstruction program is concerned with three types of forest roads—arterial roads, collector roads and local roads.

Forest arterial roads serve large land areas and usually connect with public highways or other arterial roads to form a network of primary travel routes. Location and standards for these roads are often determined by the need for travel efficiency rather than by specific resource needs. About 5% of the transportation system on the National Forest System lands are arterial roads.

Forest collector roads serve smaller land areas and usually connect to forest arterials or public highways. These roads collect traffic from forest local roads. Location and standards are determined by long-term resource needs and travel efficiency. About 20% of the transportation system are collector roads.

Forest local roads connect terminal facilities such as log landings and recreation sites, with forest collector roads, forest arterial roads, or public highways. Location and standards are determined by the specific resource needs that the roads serve. About 75% of the transportation system are local roads.

The Forest Road Program also finances multipurpose roads on or adjacent to the national forests. Actual construction or reconstruction of forest roads may also be financed under the Purchaser Credit Program and the Purchaser Election Program. These programs usually fund construction and reconstruction only of forest collector or forest local roads. Appropriated funds for the survey, design, and construction engineering costs are funded by the forest road program or, for salvage sales, by the salvage sale fund.

Under the Purchaser Credit Program timber sale contracts require the purchaser to construct roads needed to remove the timber purchased. There is no appropriation for purchaser credit roads. Instead, the amount of timber sales revenue paid by the timber purchaser and received by the U.S. Treasury is reduced by an amount equal to the cost of roads. Construction and reconstruction under the Purchaser Credit Program is accounted for outside of the Forest Service budget, but Congress sets a limit each fiscal year.

The construction of roads under the purchaser election program is described below in the section on Permanent Appropriations Programs.

Trail construction.—The priority objectives of the trail construction program are to improve trail user information and signs and to redevelop the trail system to better meet uses and needs. The redevelopment emphasizes reconstruction and relocation of trails that are substandard as a result of age, heavy use, location, or lack of maintenance. Reconstruction often includes replacing bridges, developing trailhead facilities to accommodate vehicles, providing drainage structures, and removing barriers that prevent use by disabled people.

Land Acquisition

The primary purpose of the Land Acquisition Program is to acquire lands, waters, and other related interests for recreation, wilderness, wildlife habitat management, endangered species protection, and public outdoor recreation purposes. Some lands are acquired for administrative purposes and for watershed protection.

The acquisitions are made under the authorities in the Weeks Law of 1911,[20] the Wilderness Act of 1964,[43] the Land Acquisition Act of 1925,[61] the Wild and Scenic Rivers Act of 1968,[69] the National Trails System Act of 1968,[67] the Endangered Species Act of 1973,[64] the Eastern Wilderness Act of 1975,[44] and other special acts. The Land and Water Conservation Fund Act of 1964[68] provides funding for the acquisition of recreational lands and interests.

The acquisition program includes the management of land donations and interchanges. Donations of lands or interests therein are encouraged and accepted to consolidate the national forests, improve resource management, and to obtain lands needed for research or administrative purposes. Donations may be accepted under the Clarke-McNary Act of 1924,[7] The Land Acquisition Act of 1925[61] and other legislation.

Land interchanges entail the transfer of jurisdiction of federal lands or interest therein between federal agencies. Interchanges are made to improve landownership patterns, simplify management, reduce costs, and improve service to the public.

Other Appropriations

Besides the appropriations for the programs for the National Forest System described above, there are several additional programs—acquisition of lands for national forests, special acts; acquisition of lands to complete land exchanges; miscellaneous trust funds; and range betterment funds—carried out with appropriated funds.

Acquisition of lands for national forests, special acts.—This program is directed at acquiring lands within critical watersheds needing soil stabilization and restoration of vegetation, to prevent serious erosion and resulting damage by floods. Funds may also be used for cash equalization in land exchanges involving acquisition of such lands. This type of acquisition is authorized by several special acts.[70]

Acquisition of lands to complete land exchanges.—The objective of this program is to acquire lands suitable for National Forest System purposes to replace National Forest System lands acquired by public school districts, public school authorities, or state or local governments. Such acquisition are authorized by the Sisk Act of 1967.[71]

Miscellaneous trust funds.—This program administers gifts and bequests for forests and rangelands. The available funds, $90,000 in fiscal 1988, are used to sponsor a Heritage Chair scientist(s) to conduct research on areas such as wood utilization, forest insects and disease, or forest economics; and to finance related research symposia. Balances not needed for recurrent operations are invested in interest-bearing securities.

Range Betterment Fund.—The objective of this program is to arrest range deterioration and improve range forage conditions with resulting benefits to livestock

production, watershed protection, and wildlife. Range betterment activities involve installing both structural and nonstructural range improvements. These include seeding, fence construction, weed control, water development, and fish and wildlife habitat enhancement. The program is authorized by the Federal Land Policy and Management Act of 1976[72] and the Public Rangelands Improvement Act of 1978.[73]

Permanent Appropriations Programs

All the National Forest system programs covered by the preceding material are funded through an annual appropriation act. There are also programs authorized by Congress on a continuing or permanent basis which are funded by receipts from various sources. These include brush disposal; timber roads, purchaser elections; timber salvage sales; Tongass Timber Supply Fund; operation and maintenance of Forest Service quarters; and two other small programs—licenses, and restoration of forest lands and improvements.

Brush disposal.—The objective of the brush disposal program is to dispose of brush and other debris resulting from cutting operations which may increase the fire hazard, impair reforestation, contribute to the buildup of insect populations, look unsightly, or limit recreational access. When disposal of brush and other debris from timber sale operations is necessary, national forest timber sale contracts require treatment or deposit of funds for treatment of debris. When economical and expedient, the work is done by the timber purchaser. The work can also be carried out by the Forest Service using deposits collected from the purchaser to cover costs of the work. Authorization for this program is contained in the Act of August 11, 1916[74] as amended by the Granger-Thye Act of 1950.[12]

Timber roads, purchaser elections.—The purpose of this program is to build timber sale roads on the national forests (except in Alaska) for small business purchasers who elect to have the roads built by the Forest Service. This program is authorized in the National Forest Management Act of 1976.[2]

Timber salvage sales.—The objective of this program is to salvage insect-infested, dead, damaged, or down timber, and to remove associated trees for stand improvement.

A separate permanent appropriation for timber salvage was established for this program as a result of the National Forest Management Act of 1976. Part of the receipts from timber salvage sales are deposited in this account and used to prepare and administer future salvage sales.

Separate appropriations of $3 million each in fiscal years 1977 and 1979 were used as "seed money" to accelerate the establishment of "timber salvage sales" as a self-sustaining permanent appropriation.

In fiscal year 1988, Congress appropriated an additional $37 million and provided that the funds shall be merged with and made a part of this appropriation. This is to accommodate the salvage program generated by the severe fire damages of 1987.

Tongass timber supply fund.—In 1980 Congress directed the Forest Service, through the Alaska National Interest Lands Conservation Act,[75] to maintain the timber supply from the Tongass National Forest to dependent industry at a rate of 4.5 billion board feet per decade.

The Tongass Timber Supply Fund was created as a result of Congressional wishes to designate wilderness on the Tongass National Forest while maintaining an existing viable timber industry. The designated timber supply is sufficient to maintain the industry's timber harvest level at a rate similar to the mid- to-late 1970s, the time immediately preceding the passage of the Alaska National Interest Lands Conservation Act.

Before fiscal year 1988, the budget for the Tongass National Forest consisted of funding annually appropriated to the Forest Service from the National Forest System and Construction Appropriations and through Permanent Appropriations and Trust Funds.

Most of the funding available to the Tongass National Forest was derived from receipts collected by the Secretaries of the Interior and Agriculture and provided through the Tongass Timber Supply Fund.

In fiscal year 1988, Congress directed that all funds for the Tongass National Forest be derived from the Tongas Timber Supply Fund. In fiscal year 1989, the Budget Reconciliation Act of 1987,[76] directed that the Tongass Timber Supply Fund be funded by an annual appropriation rather than a permanent appropriation.

Operation and maintenance of Forest Service quarters.—The purpose of this program is to operate and maintain Forest Service employee quarters.

The Continuing Appropriations Act of 1985, Interior and Related Agencies Appropriations[77] provided authority for the establishment of a permanent fund for deposit of Forest Service employee payroll deductions for quarters rental. Funds are used to operate and maintain employee quarters on the unit from which collected. These funds are in addition to the maintenance of facilities funds in the National Forest System annual appropriations.

Other permanent funds.—Besides programs described above there are two other small programs—the Smokey Bear and Woodsy Owl licenses programs and the Restoration of Forest Lands and Improvements programs—funded under permanent appropriations.

Under the licenses program, fees for the use of the Smokey Bear and Woodsy Owl characters by private enterprises are collected under regulations formulated

by the Secretary of Agriculture. They are available to fund the nationwide fire prevention campaign, programs to promote the wise use of the environment, and programs that foster maintenance and improvement of environmental quality.

The Restoration Program includes recoveries from cash bonds or forfeitures under surety bonds by permittees or timber purchasers who fail to complete performance or improvement, protection, or rehabilitation work required under the permit or timber sale contract.

The Recovered Funds are used to cover the cost to the Government of completing the work on National Forest System lands. Funds received as settlement of a claim are used for improvement, protection, or rehabilitation made necessary by the action which led to the cash settlement.

Trust Funds Programs

Besides the programs described above, funded by annual and permanent appropriations, there are several National Forest System programs funded by trust funds. These are the Knutson-Vanderburg (K-V) programs, cooperative programs and the reforestation programs.

Knutson-Vanderburg programs.—The Knutson-Vanderburg Act of 1930, as amended,[78] provides that part of the receipts from timber sales may be used for needed reforestation, timber stand improvement, and to protect and improve all other resource values on timber sales areas. As shown in table 3 most of the Knutson-Vanderburg funds are used to reforest sales areas.

Cooperative work, other.—The Cooperative Funds Acts of 1914,[56] the Granger-Thye Act of 1950,[12] the National Forest Roads and Trails Act of 1964[66] and other acts authorize the use of deposits received from cooperators for the construction, reconstruction and maintenance of roads, trails and other improvements; for scaling services; fire protection and other resource purposes on National Forest System lands.

The Granger-Thye Act also authorizes the acceptance of deposits for administering and protecting nonfederal land within or near National Forest System land. The program funded with such monies include in large part management, reforestation, fire protection, and road maintenance.

The Forest and Rangeland Renewable Resource Research Act of 1978[9] authorizes the acceptance of deposits from state and other public agencies, industrial associations, and other private agencies to finance research projects of mutual interest and benefit.

Reforestation trust fund.—The Recreational Boating Safety and Facilities Improvement Act of 1980[79] established a trust fund for reforestation and timber stand improvement on National Forest System lands when appropriated funds do not meet the total needs of fiscal year programs. The objective is to prevent the build-up of work back logs. The funds are held by the Secretary of the Treasury and provided to the Secretary of Agriculture based on the estimated needs to accomplish the treatment of the acreage in the reforestation and timber stand improvement programs.

National Forest System Administration

The National Forest System programs described above are directed at the National level by a Deputy Chief for the National Forest System. This Deputy Chief and the supporting headquarters staff have multiple responsibilities. They are responsible for the formulation and administration of national programs for the National Forest System; coordination with other federal departments and agencies, states, and other organizations; and program review and general direction of the work carried out at the regional offices of the Forest Service, the national forests and other centers of National Forest System programs.

The major part of program activities is carried out through a decentralized field organization that includes nine regional offices located at:

Atlanta, GA (R-8)	Albuquerque, NM (R-3)
Denver, CO (R-2)	Juneau, AK (R-10)
Odgen, UT (R-4)	Portland, OR (R-6)
Milwaukee, WI (R-9)	Missoula, MT (R-1)
San Francisco, CA (R-5)	

On-the-ground management of resources is conducted through a system of 156 national forests, 19 grasslands, and 19 land utilization projects.

The management of National Forest System resources involves complex resource, economic, and social problems. To deal with these problems the Forest Service employs people trained in a wide range of fields such as forestry, range management, wildlife management, engineering, recreation, landscape architecture, economics, accounting and personnel management. Employment in fiscal year 1988 totaled 23,414 person years. Most of these people were directly involved in the management of the resources on the National Forests.

Sharing of National Forest System Receipts with States and Local Governments

The National Forest System programs generate substantial receipts to the U.S. Treasury from timber sales and other land uses. In fiscal year 1988 estimated receipts totaled $898 million. Additional receipts were

obtained from mineral leases on National Forest System lands under programs for which the Bureau of Land Management has administrative and fiscal responsibility.

The counties in which National Forest System lands are located share these receipts, for the most part under the Twenty-five Percent Fund Act of May 23, 1908,[80] and the Weeks Law of 1911.[20] These provide that 25% of all monies received from each national forest is to be paid to the state in which the national forest is situated, for the benefit of public schools and public roads of the county or counties in which the national forest is situated. The Bankhead-Jones Farm Tenant Act of 1937[42] also provided that 25% of the net revenue from the use of national grasslands and other Title III lands shall be paid to the county or counties in which the land was acquired, for use for schools and roads.

The National Forest Management Act of 1976[2] defined the term "monies received" from use of National Forest System lands to include all collections for sale areas betterment activities, and all amounts earned or allowed any purchaser of national forest timber and other forest products, as purchaser credits for the construction of roads.

Receipts from disposal of common varieties of minerals on National Forest System lands and from mineral leases on acquired lands are similarly shared with states and counties under the Common Varieties of Minerals Materials Act of July 31, 1947,[53] and under the Mineral Leasing Act for Acquired Lands of 1947.[48] For receipts from other mineral leases and related mineral disposals, for which the Bureau of Land Management in the Department of the Interior is responsible, such receipts are also shared with counties of origin. Payments from these receipts are made to the state and counties by the Bureau of Land Management.

Special payments to certain states are provided for in special Acts, including the Boundary Waters Canoe Area Act of 1978[26] for Minnesota, and the Act of June 20, 1910[81] for Arizona and New Mexico. Provisions for assuring minimum levels of federal payments to local governments in counties where public lands are located also were contained in the Payments in Lieu of Taxes Act of 1976.[82]

Relationships with Other Forest Service Programs

Within the Forest Service, the National Forest System is closely coordinated with related programs of State and Private Forestry. All regional foresters and national forest supervisors are responsible for working with State and Private Forestry to implement the most efficient technology for harvesting. National Forest System is a prime cooperator in fire and pest protection and regional timber supply programs which involves state and private interspersed or adjacent lands.

In addition every regional rorester and national forest supervisor represents and presents the State and Private Forestry program to the cooperating states, local governments, and private forest owners. As such, the National Forest System is a major part of the means by which technical and financial assistance are delivered to other federal agencies, state and local governments, and private forest land owners.

Relationships With Other Agencies

Besides close working relationships within the Forest Service in carrying out programs of research and cooperative forestry, as described in preceding sections, the Forest Service cooperates with many federal, state, and private organizations in the management of the National Forest System.

Soil Conservation Service.—The Forest Service works closely with the Soil Conservation Service on projects dealing with watershed protection and improvement. Watershed improvement work conducted on designated watersheds under the Flood Control Act of 1944[83] and the Watershed Protection and Flood Prevention Act of 1954[16] is closely coordinated with related activities of the Soil Conservation Service on adjoining private or nonfederal public lands. Soil surveys conducted by the Forest Service on National Forest System lands are similarly coordinated with the Soil Conservation Service which has federal leadership for soils. The Forest Service also cooperates in Soil Conservation Service snow surveys, a large part of which involves snow packs on national forest lands, and with conservation districts in planning and carrying out soil and water conservation programs and range management programs in districts that involve National Forest System lands.

Collection of data on water resources by the Forest Service is coordinated with related federal programs in the U.S. Department of the Interior.

Animal and Plant Health Inspection Service.—The Forest Service cooperates with the Animal and Plant Health Inspection Service and other sederal, state, and county agencies in enforcing livestock quarantine and testing programs to prevent spread of contagious diseases of animals. Somewhat related programs for control of noxious farm weeds on National Forest System lands are largely handled through cooperation with State and county weed control organizations, as authorized in the Carlson-Foley Act of 1968[65] and the Federal Noxious Weed Control Act of 1974.[84]

U.S. Bureau of Mines.—The Forest Service works with the U.S. Bureau of Mines in a variety of ways. These

include: supplying mineral material production data; jointly conducting mining feasibility studies; integration of data supplied by the Bureau into land management planning; material assistance in acquisition of geologic field data; and use of material supplied by the Bureau to identify mineral industry events, trends, and issues.

The Bureau of Land Management.—The complex relationship between the Forest Service and the Bureau of Land Management in managing locatable and leasable mineral resources on National Forest System lands varies with the statutory authority involved. These authorities vary not only by the commodities involved but also from location to location; the specific management roles of the two agencies vary accordingly.

Regardless of the authorities involved, the bulk of the administration dealing with locatable and leasable mineral activities on National Forest System lands is carried out by the Forest Service. For example, the Forest Service jointly administers the general mining laws with the Bureau of Land Management on those portions of the National Forest System lands that were formerly public domain lands. The Forest Service's role involves evaluating and authorizing each specific industry proposal for locatable mineral exploration, development, production, and site reclamation. It also conducts mineral examinations to determine the validity of mining claims. The Bureau of Land Management keeps track of land status, mining claims and related mining filings, and issues patents for qualifying mining claims.

In the administration of grazing resources, where ranch operators use lands administered by both the National Forest System and Bureau of Land Management, and where National Forest System grazing lands are mingled with public domain and private lands, grazing management programs are coordinated through memoranda of agreements involving the Forest Service, the Bureau of Land Management, the Soil Conservation Service, and conservation districts. Such coordination involves such matters as seasonal use of related ranges, issuance of permits, and grazing practices.

Fire control on Bureau of Land Management lands that are mingled with or adjacent to national forests is often handled by the Forest Service under cooperative agreements. Cooperative fire training and control facilities in Boise, ID, were also jointly developed by the Bureau of Land Management, the Forest Service, and other agencies.

In Oregon, the Forest Service manages certain intermingled revested Oregon and California railroad grant lands under a special arrangement whereby receipts received by the Forest Service are transferred to the Department of the Interior for distribution to counties, under the Act of June 24, 1954.[85]

Cadastral surveys to establish land lines and boundaries for federal lands are made by the Bureau of Land Management for lands reserved from public domain, with funding from the Forest Service for work on National Forest System lands. The Bureau of Land Management also is responsible for maintaining land records for all federal public lands.

The U.S. Geological Survey.—This agency conducts a broad program of surveys, including the classification of lands as to their value for minerals and for reservoir and waterpower sites. Surveys of water resources conducted in cooperation with other agencies provide data on the quantity, quality, and use of the Nation's water resources. The Geological Survey also has major responsibility for a national program to prepare base maps showing topography, land development, and vegetation. Primary base maps for National Forest System lands are prepared and periodically revised in a coordinated program of the Geological Survey and the Forest Service.

Office of Surface Mining Reclamation and Enforcement.—This agency is responsible for developing, implementing, and enforcing surface mining and reclamation standards, and is responsible for reclaiming abandoned mined lands as authorized by the Surface Mining Control and Reclamation Act of 1977.

National Park Service.—Cooperation between the Forest Service and the National Park Service includes the designation and marking by the Park Service of historic, cultural, and other landmarks on lands administered by the Forest Service under the Historic Preservation Act of 1966,[86] which established the historic preservation program. Some national monuments that are located within national forest boundaries also are administered by the Park Service.

Fish and Wildlife Service.—The research program of the Fish and Wildlife Service provides information that aids in the management of National Forest System lands. This agency also is responsible for federal predator and animal damage control projects on National Forest System lands, although only after the Forest Service has given approval. The Fish and Wildlife Service administers the Endangered Species Act of 1973[64] under which all federal agencies must manage resources so as to protect endangered and threatened species. The Fish and Wildlife Service also administers grant programs with the states under the Pittman-Robinson Act of 1937[87] and the Dingell-Johnson Act of 1950.[88] Certain wildlife habitat improvement work done by state fish and game commissions on National Forest System lands is made possible by these federal grant programs.

Bureau of Reclamation.—Water development projects of the Bureau of Reclamation have varied impacts on management of adjacent National Forest System

lands, including administration of special use permits for powerlines or other facilities. In certain cases, the Bureau and the Forest Service also have developed agreements whereby the Forest Service is responsible for the planning and administration of recreation facilities developed in connection with reclamation projects.

Federal Highway Administration.—This agency in the Department of Transportation is responsible, in cooperation with the Forest Service and state highway agencies, for the planning and construction of forest highways. Such highways are main traffic arteries that connect or provide access to national forests, and are of major importance to states, counties, and local communities. In accordance with the Federal Aid Highway Act of 1973,[89] appropriations for forest highways are allotted and administered in conformity with regulations and plans jointly approved by the Secretaries of Transportation and Agriculture. Forest Service administrative expenses in connection with the planning and approval of construction projects and related measures to assure protection of National Forest System resources are covered by transfer of funds from the Department of Transportation.

Council on Environmental Quality.—The Environmental Policy Act of 1969[46] requires the preparation of Environmental Impact Statements for any "major action" proposed by federal agencies, including actions affecting the use, management, and protection of National Forest System resources. These statements are submitted to the Council on Environmental Quality after extensive review by other agencies and the public. This requirement entails a major program in the Forest Service in terms of manpower, time, and funding.

Environmental Protection Agency.—Several laws administered by this agency influence the management of National Forest System resources. Under the Federal Water Pollution Control Act of 1972[32] and later amendments in 1977, the Forest Service cooperates with the Environmental Protection Agency and state water control agencies in planning for "best management practices" and in meeting other requirements for protection of water quality. All federal agencies are required to comply with federal, state, and local requirements for the control and abatement of water pollution at federal installations. The Clean Air Act Amendments of 1977[90] require federal agencies to meet federal, state, and local requirements for control of air pollution in logging slash disposal and other fire management programs. Insect control programs on National Forest System lands also are planned and conducted according to Environmental Protection Agency standards and requirements for use of pesticides imposed under the Federal Insecticide, Fungicide, and Rodenticide Act of 1972 as amended.[91]

Corps of Engineers.—Cooperative arrangements with the Corps of Engineers in the Department of the Army provide for Forest Service administration of recreation on certain lands in the National Forest System that are affected by Corps of Engineers reservoir construction projects and for the interchange of land for administrative purposes around Corps impoundment projects.

Public Health Service.—Developed recreation sites on National Forest System lands are subject to inspection by the Public Health Service in the Department of Health, Education and Welfare. Such facilities may be closed by the Service where pollution abatement facilities are inadequate.

Small Business Administration.—This agency cooperates with the Forest Service in a program of "set aside" sales of national forest timber under the Small Business Act of 1958[60] to assure that "small" businesses, defined as less than 500 employees, obtain a fair share of the available sales of national forest timber.

Federal Power Commission.—The Forest Service prepares stipulations which it recommends to the Federal Power Commission for inclusion in licenses issued by the Commission for water power developments. Those stipulations are designed to protect National Forest System resources that may be affected by power developments.

General Service Administration.—Many of the administrative tasks of the Forest Service are handled with or through the General Services Administration, including the construction and operation of many buildings used by the Forest Service, procurement of supplies, use and disposal of property, management of transportation and communications equipment and facilities, management of automatic data processing facilities, management of archives and records centers, and the publication of laws and administrative documents.

State Fish and Game Departments.—The management of fish and wildlife habitats on National Forest System lands is closely coordinated with programs of state fish and game departments which have the responsibility for management of wildlife and fish populations, including such measures as setting hunting and fishing seasons and bag limits, propagation of game and fish, and the licensing of hunters, trappers, and fishermen.

In habitat improvement work on National Forest System lands, the funding provided by direct federal appropriations through the Forest Service is often supplemented by State agencies using portions of state grants provided under the Pittman-Robinson Act of 1937[87] and the Dingell-Johnson Act of 1950.[88] State project work financed in this way covers a variety of wildlife habitat improvements, wildlife surveys, land acquisitions, and other wildlife management activities.

The Cooperative Wildlife Habitat Management Act of 1974[92] also contains provisions whereby states may

charge special fees for hunting and fishing on National Forest System lands. These fees are then made available for wildlife and fish habitat management projects on National Forest System lands under state-federal cooperative agreements. Forest Service personnel also cooperate with state, county, and other federal officials in the enforcement of laws and regulations for the protection of wildlife.

Relationships With the General Public

The growing participation of many groups and individuals in National Forest System planning and administration of resource programs has become of far-reaching importance at both national and local levels. Under the National Environmental Policy Act of 1969,[18] large numbers of Environmental Impact Statements for "major" Forest Service actions are widely reviewed not only by other federal and state agencies but also by many private organizations and individuals.

The Forest and Rangeland Renewable Resources Planning Act of 1974[1] and the National Forest Management Act of 1976,[2] likewise require public involvement in the development of resource assessments, land management plans for each unit of the National Forest System, and the formulation of Forest Service programs. Relationships with the public in these and related Forest Service activities involve public hearings and many meetings and correspondence with individuals and organizations.

Similar public participation is maintained in special project work such as the Roadless Area Review and Evaluation (RARE II) and many specific development projects. Forest Service regional offices and national forests, and other Forest Service units concerned with research and with state and private forestry programs, also work and consult with the varied interests that are concerned with Forest Service programs.

Table 4.—Forest Service funds for human resource programs, fiscal year 1988.

Program	Funds *(thousand dollars)*
Youth Conservation Corps[1]	unfunded
Job Corps	60,200[2]
Senior Community Service Employment Program	22,700[2]
Volunteers	unfunded
Hosted Programs	unfunded
Total	82,900[2]

[1]Congress directed that not less than $1 million be expended from benefiting Forest Service program funds in fiscal year 1988. Actual Forest Service funding is expected to be $1.3 million.

[2]Funds for program year July 1, 1987-June 30, 1988.

HUMAN RESOURCE PROGRAMS

The Forest Service participates in cooperative manpower programs to provide human and natural resource benefits by administering and hosting programs in work, training, and education for the unemployed, underemployed, elderly, young, and others with special needs. The fiscal year 1988 appropriation for these programs are shown in table 4.

Youth Conservation Corps

One of these programs, the Youth Conservation Corps, was established under the Youth Conservation Corps Act of 1970.[93] The Corps provides gainful summer employment and job training in conservation work for young men and women, plus a variety of educational experiences in learning to improve the productivity of forest, soil, water, and other natural resources. Youths participating in this program are between 15 and 18 years of age, and are recruited by random selection from all economic, social, ethnic, and racial backgrounds.

The conservation work-learn projects conducted under this program include such activities as the construction and maintenance of recreation facilities on National Forest System lands, range and wildlife habitat improvement work, timber stand improvement, trail construction and maintenance, visitor information services, and soil and water conservation projects. In fiscal year 1988, about 1,200 young people are expected to participate in a $1.3 million program funded from benefiting Forest Service programs. Conservation work valued at about $1.6 million will be implemented.

Job Corps

Under an agreement with the U.S. Department of Labor and by authorizations in Title 4 of the Comprehensive Employment and Training Act of 1973,[94] the Forest Service operates 18 Job Corp Centers to provide basic education and job training to disadvantaged youths. The purpose of this program is to produce graduates who are able to find productive work, re-enter school or join the military. Enrollees receive room, board, clothing, skills training, education, and a monthly allowance in lieu of wages.

During program year 1986 (July 1, 1986 to June 30, 1987), 9,097 young men and women participated in the program funded at $57.2 million. Besides acquiring job

skills which will enhance the Nation's future productivity, these Job Corps participants completed work valued at $18.3 million.

It is anticipated in program year 1987 (July 1, 1987 to June 30, 1988), about 9,242 young men and women will participate at a funding level of $57.1 million. The value of accomplished work is estimated to be $21 million.

Senior Community Service Employment Program

The Forest Service cooperates with the Department of Labor in sponsoring a Senior Community Service Employment Program under the Older American Community Service Act of 1975.[95] This program has three fundamental purposes: community service, part-time employment and supplemental income, and training and transition of participants to the private sector labor market. The program employs economically disadvantaged persons age 55 and older and fosters a renewed sense of self-worth and community involvement among traditionally poor and hard-to-employ older people.

Volunteers in the National Forests

The Volunteers in the National Forest Act of 1972[96] permits citizens to volunteer their time and talent to help the Forest Service in such work as providing information to visitors, environmental education, clearing trails, and assisting in research projects.

The program provides help in natural resource protection and management at nominal costs. The program offers people the opportunity to contribute their services to help manage the nation's natural resources.

The Touch America Program (TAP), a component of the volunteer program, includes special emphasis on participation by youth ages 14 to 17. TAP is a partnership of private sector organizations sponsoring teenage youths to do conservation work. During fiscal year 1987, 5,203 youths participated.

In fiscal year 1987, 57,298 volunteers served in the Forest Service, including TAP participants. The appraised value of their work was $23.8 million. The Forest Service covers out of pocket costs of volunteers from regular project funds. It is anticipated that there will be a participation of 58,730 volunteers participating in the program in fiscal year 1988.

Hosted Programs

The Forest Service also serves as a host agency by providing work opportunities for programs primarily administered by State and local governments. Hosted programs include employment under the Job Training Partnership Act, College Work Study, Vocational Work Study and Work Incentive. In fiscal year 1987, 761 person-years of work were completed, valued at $9.5 million. There were 6,568 participants in these programs. In fiscal year 1988, it is expected that 7,000 people will participate in hosted programs doing conservation work valued at about $10 million.

ENDNOTES

[1]88 Stat. 476 as amended; 16 U.S.C. 1601 (note), 1600-1614.

[2]90 Stat. 2949 as amended; 16 U.S.C. 1600 (note).

[3]U.S. Department of Agriculture, Forest Service. An Assessment of the Forest and Range Land Situation in the United States. For. Resour. Rep. 22. Washington, DC: U.S. Department of Agriculture, Forest Service. 352 p., 1981.

[4]U.S. Department of Agriculture, Forest Service. The Principal Laws Relating to Forest Service Activities. Ag. Handbook 453. Washington, DC: U.S. Department of Agriculture, Forest Service. 591 p., 1983.

[5]U.S. Department of Agriculture, Forest Service. [In press] Report of the Chief of the Forest Service Fiscal Year 1987. Washington, DC: USDA Forest Service.

[6]U.S. Department of Agriculture, Forest Service. [processed] 1989 Budget Explanatory Notes for Committee on Appropriations. U.S. Department of Agriculture, Forest Service.

[7]43 Stat. 653 as amended; 16 U.S.C. 499, 505, 568, 568a, 569, 570.

[8]45 Stat. 699 as amended; 16 U.S.C. 581, 581a, 581a-l, 581-b, 581-c.

[9]92 Stat. 353 as amended; 16 U.S.C. 1600 (note), 1641 (note), 1641-1647.

[10]7 U.S.C. 361a-i.

[11]76 Stat. 806 as amended; 16 U.S.C. 582a, 582a-1-582a-7.

[12]64 Stat. 82 as amended; 16 U.S.C. 581i-l.

[13]72 Stat. 1793; 42 U.S.C. 1891-1893.

[14]91 Stat. 913; 7 U.S.C. 1354, 2669.

[15]91 Stat. 1407; 16 U.S.C. 2001-2009.

[16]68 Stat. 666; 16 U.S.C. 100 (note), 1001-1008; 33 U.S.C. 701b (note).

[17]90 Stat. 2743 as amended; 43 U.S.C. 1701 (note) et. seq.; 16 U.S.C. 478a, 1338a.

[18]83 Stat. 852; 42 U.S.C. 4321 (note) 4321, 4331-4335, 4341-4347.

[19]78 Stat. 329 as amended; 42 U.S.C. 1916 et. seq.

[20]36 Stat. 961 as amended; 16 U.S.C. 480, et. seq.

[21]38 Stat. 373 as amended; 7 U.S.C. 351-9.

[22]50 Stat. 188.

[23]64 Stat. 473 as amended; 16 U.S.C. 568c, 568d.

[24]86 Stat. 657; 7 U.S.C. 2669.

[25]92 Stat. 365; 16 U.S.C. 2101 (note), 2101-2110, 1606, 2111.

[26]92 Stat. 1649; 15 U.S.C. 1132.

[27]58 Stat. 887 as amended by 68 Stat. 666 and 76 Stat. 808; 33 U.S.C. 701b; 16 U.S.C. 1004.

[28]49 Stat. 1148 as amended; 16 U.S.C. 590g et. seq.

[29]52 Stat. 1215 as amended; 33 U.S.C. 701b-l.

[30]76 Stat. 605; 16 U.S.C. 540a and 7 U.S.C. 351-9.

[31]91 Stat. 1567; 33 U.S.C. 1288.

[32]58 Stat. 736; 16 U.S.C. 580a.

[33]86 Stat. 657 as amended; 7 U.S.C. 266-70.

[34]90 Stat. 982; 7 U.S.C. 3004.

[35]92 Stat. 349; 16 U.S.C. 1600 (note), 1670 (note), 1671-1676.

[36]87 Stat. 221; 16 U.S.C. 1503, 1504, 1510.

[37]99 Stat. 1354; 7 U.S.C. 1281.

[38]26 Stat. 1103; 16 U.S.C. 471.

[39]Hough, Franklin B. Report upon forestry. Gov. Print. Off., Washington, DC: vol. I, 650 p. 1878; vol. II, 618 p., 1880; vol III, 318 p; 1882.

[40]30 Stat. 11 as amended; 16 U.S.C. 473-475, 477-482, 551.

[41]74 Stat. 215; 16 U.S.C. 528 (note), 528-531.

[42]50 Stat. 522 as amended; 7 U.S.C. 1010-1012; 16 U.S.C. 551.

[43]78 Stat. 890; 16 U.S.C. 1121 (note), 1131-1136.

[44]88 Stat. 2096; 16 U.S.C. 1132 (note).

[45]92 Stat. 40; 16 U.S.C. 1132.

[46]83 Stat. 852 as amended; 42 U.S.C. 4321, 4331-5, 4341-7y.

[47]41 Stat. 437 as amended; 30 U.S.C. 181.

[48]81 Stat. 913; 30 U.S.C. 351-359.

[49]91 Stat. 445; 30 U.S.C. 1201, 1236, 1272, 1305.

[50]84 Stat. 1566; 30 U.S.C. 1001 et. seq.

[51]17 Stat. 91; 30 U.S.C. 22, 28, 28b.

[52]69 Stat. 369 as amended; 30 U.S.C. 613-5.

[53]61 Stat. 681 as amended; 30 U.S.C. 601-4, 611.

[54]74 Stat. 205; 7 U.S.C. 2201 (note).

[55]42 Stat. 465; 16 U.S.C. 485, 486.

[56]38 Stat. 415 as amended; 16 U.S.C. 498.

[57]85 Stat. 303; 16 U.S.C. 551a.

[58]100 Stat. 3206; 21 U.S.C. 801.

[59]92 Stat. 32 as amended; 16 U.S.C. 472a(e).

[60]43 Stat. 384 as amended; 15 U.S.C. 631 et. seq.

[61]43 Stat. 1132 as amended; 16 U.S.C. 555, 557, 572.

[62]94 Stat. 2987; 16 U.S.C. 470 et. seq.

[63]93 Stat. 721; 16 U.S.C. 470aa-ii.

[64]87 Stat. 884 as amended; 16 U.S.C. 1531-1536, 1538-1540.

[65]82 Stat. 1146; 43 U.S.C. 1241.

[66]78 Stat. 1089 as amended; 16 U.S.C. 532-538.

[67]82 Stat. 919 as amended; 16 U.S.C. 1241 (note), 1241-1249.

[68]78 Stat. 897; 16 U.S.C. 460 (note) et. seq.

[69]82 Stat. 906 as amended; 16 U.S.C. 1271 (note) 1271-1287.

[70]54 Stat. 297 and 299; 58 Stat. 227.

[71]81 Stat. 531 as amended; 16 U.S.C. 484a.

[72]90 Stat. 2743 as amended; 43 U.S.C. 1701 (note), et. seq.

[73]92 Stat. 1806; 43 U.S.C. 1752-53, et. seq.

[74]39 Stat. 446 as amended; 16 U.S.C. 490.

[75]94 Stat. 2371; 16 U.S.C. 3210.

[76]100 Stat. 1330; 7 U.S.C. 1421.

[77]98 Stat. 1874; 5 U.S.C. 5911 (note).

[78]46 Stat. 527 as amended; 16 U.S.C. 576-576b.

[79]94 Stat. 1983; codified as amended in scattered sections of 16 U.S.C.

[80]35 Stat. 251 as amended; 16 U.S.C. 500; 16 U.S.C. 553; 31 U.S.C. 534.

[81]61 Cong. ch. 310 p 573, 601.

[82]90 Stat. 2662; 31 U.S.C. 1601-1607.

[83]58 Stat. 887 as amended; 33 U.S.C. 701-1

[84]88 Stat. 2148; 7 U.S.C. 2801-2 (note).

[85]68 Stat. 271; 43 U.S.C. 1181 f-g.

[86]80 Stat. 915; 16 U.S.C. 470a, 470f, and 470j.

[87]50 Stat. 917; 16 U.S.C. 669-669j.

[88]68 Stat. 430; 16 U.S.C. 777.

[89]87 Stat. 250; 23 U.S.C. 101 et. seq.

[90]91 Stat. 685; 42 U.S.C. 7401 et. seq.

[91]86 Stat. 973 as amended; 7 U.S.C. 136, 136b, 136i-m, 136p.

[92]88 Stat. 1369; 16 U.S.C. 670a-o.

[93]84 Stat. 794 as amended; 16 U.S.C. 1701-1706.

[94]87 Stat. 839 as amended; 29 U.S.C. 801-992.

[95]89 Stat. 720; 42 U.S.C. 3056.

[96]86 Stat. 147; 16 U.S.C. 558a (note) 558a-558d, 558d.

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